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ON SOME STRUCTURAL FEATURES OF THE METAGALAXY.

(George Darwin Lecture, delivered by Dr. Harlow Shapley, Assoc.R.A.S., on 1934 May 11.)

1. *Outline and Summary.*—Progress in a group of investigations designed to discover some of the structural details in individual galaxies and in the Metagalaxy is reported in the following pages.

(*a*) The first section is concerned with the distribution of cluster-type Cepheids in high galactic latitude. To the 169 already known in latitudes greater than or equal to ± 20°, the systematic variable star programme carried on at Harvard has added 312, mostly fainter than magnitude 13·0. With allowance for absorption and for uncertainties yet remaining in the mean absolute magnitude of these stars, the thickness of the Milky Way, so far as this type of star is concerned, is not less than twenty-five kiloparsecs ; he extent of the Milky Way in its own plane, by the same criterion, is more than thirty kiloparsecs, perhaps much more.

(*b*) The extent of the Milky Way in the anti-centre quadrant is considered on the basis of classical and cluster-type Cepheids ; provisionally it is found that the galactic system reaches to a distance of at least ten kiloparsecs in longitude 150°.

(*c*) More than six hundred new variables have been found in the Large Magellanic Cloud and measured for position, ranges and median magnitudes ; the frequency of periods is not unlike that for the classical Cepheids in the galactic system ; the light curves also are comparable in all details. The Magellanic Cepheids, like the galactic classical Cepheids, are concentrated in regions of high star-density.

(*d*) Further study of the period-luminosity relation in the Large Magellanic Cloud permits its revision and strengthening for the Cepheids of highest absolute magnitude. An observed deviation from the relation that had previously been found for the Small Cloud is probably to be attributed to scale error in the magnitude system. No seriously disturbing

effects of light absorption in the Cloud on the magnitudes of the Cepheids has as yet been found.

(*e*) The angular diameter of the Large Magellanic Cloud, heretofore taken as 7°·2, is now shown by star counts, by microdensitometer tracings on small-scale long-exposure plates, and especially by the distribution of newly found outlying globular and open clusters, to be at least twelve degrees, corresponding to a linear diameter of 5·5 kiloparsecs. From similar tracings the diameter of the Small Cloud is increased from 3°·6 to 8°·0.

(*f*) The spectra of some three thousand stars spread over the face of the Large Magellanic Cloud have been classified by Miss Cannon. Those which are members of the Cloud are chiefly the supergiants of Classes O, B, A and M, with absolute magnitudes brighter than −4·0. The most luminous objects that are certainly members of the Cloud are the seventy-five Class B stars of apparent magnitudes 9 to 11 ; with absolute magnitudes between −6 and −8 they are, as constant energy radiators, supreme among known stars.

(*g*) Continuing the inquiries into faint extensions of galaxies, as shown by the new dimensions of the Magellanic Clouds and by the distribution of cluster-type Cepheids in the Galaxy, we find for the Andromeda Nebula, by means of densitometer tracings on small-scale plates of long exposure, a length of 4°·5 and a width of nearly 4°, thus increasing the projected area by ten times over that shown in the usually published photographs. The tracings indicate that, although the length is four times the width for the projection of the brighter part of the nebula, the object is almost spherical in terms of light that is near the limit of registration.

(*h*) Preliminary densitometer work on other bright galaxies shows that the dimensions that are registered on long-exposure plates with the Bruce 24-inch and the Metcalf 16-inch refractors are, for spheroidal systems, on the average something like five times the dimensions heretofore published ; and for the spirals about 2·3 times.

(*i*) Direct visual estimates on Bruce plates of the dimensions of 488 galaxies brighter than 13·0 provide homogeneous data for the comparative study of systems in a small range of apparent magnitude (10·5 to 13·0). The large disparity in the linear dimensions of spiral and spheroidal systems heretofore accepted is found to be illusory, especially when attention is turned to galaxies of the Virgo group, where differences in distances do not affect the interpretation of the measures.

(*j*) With the census of galaxies brighter than the thirteenth magnitude completed, we have continued the "eighteenth magnitude" survey, and have now found approximately 125,000 new galaxies on long-exposure plates made with the 24-inch telescope at Bloemfontein and the 16-inch at Oak Ridge ; one-third of the whole sky has been covered. In three sections of the sky work has been completed on the distribution, magnitudes, diameters, form and concentration for approximately twelve thousand individual systems. Five general surveys of galaxies are described.

(*k*) The dependence of nebular frequency on galactic latitude and longitude has been studied in detail at Harvard, and the results, showing very little change from latitudes +30° and −30° to the north and south

galactic poles respectively, are in essential agreement with results derived at Mount Wilson from a similarly extensive survey.

(*l*) A special study of the magnitudes of ten thousand galaxies in the equatorial belt $\delta = +22°$ to $\delta = -20°$ has resulted in a series of luminosity curves which illustrate conspicuous irregularities in the distribution of galaxies, and show as well that the higher space density of galaxies in the northern galactic hemisphere tends to disappear at about magnitude 18. The search for a possible metagalactic density gradient reveals the existence of some very extended concentrations of galaxies in certain regions of the sky—metagalactic clouds with diameters of the order of fifty megaparsecs and populations in the tens of thousands, and therefore of higher dimensional order than the rather frequent groups of galaxies.

(*m*) Luminosity curves have been determined for nearly thirty groups of galaxies, most of which are incompletely surveyed because of the magnitude limitations of the telescopes. A detailed study of the Wolf "Nebelnest" in Coma gives its distance as over seventeen megaparsecs, its diameter approximately half a megaparsec, its population five hundred galaxies, its photographic magnitudes almost wholly between fourteen and nineteen with maximum frequency at 16·7, and the density of matter in space throughout the cluster of the order of 10^{-27} grammes per cubic centimetre. This value of the density agrees satisfactorily with data for other groups of galaxies, and is more than a hundred times the average density in metagalactic space.

2. *Thickness of the Galaxy.*—It is generally recognized that the space density of stars is very low at distances greater than five hundred parsecs from the galactic plane, except perhaps in the region of the galactic centre. Classical Cepheids, Class B and Class O stars, planetary nebulæ and other objects that show pronounced galactic concentration are scarce in the higher galactic latitudes ; but the cluster-type Cepheids and long-period variables are relatively numerous there, and practically all that are fainter than the tenth magnitude, in latitudes greater than $\pm 40°$, are more than a thousand parsecs from the plane. These widely dispersed variables therefore become our best direct means of finding the total thickness of the Milky Way.

The work at Harvard and at Mount Wilson on the distribution of external galaxies * demonstrates the absence of serious space absorption in latitudes higher than 30° ; and recent studies at the Harvard Observatory on the proper motions of cluster-type Cepheids greatly strengthen the conclusion that the median photographic absolute magnitude of these variable stars can be put near zero.† Gerasimovič has shown how this cluster variable work and that of many years ago on the absolute magnitudes of the brighter classical Cepheids can be harmonized with more recent studies of the motions of fainter classical Cepheids, whose magnitudes are affected by absorption near the galactic plane.‡ By these proper motion studies we have thus

* *Harv. Bull.*, 889, 1932 ; *Harv. Reprint*, No. 90, 1933 ; *Mt. Wilson Contr.*, 485, 1934 ; sections 12 and 13 below.

† P. F. Bok and C. D. Boyd, *Harv. Bull.*, 893, 1933.

‡ *Observatory*, 57, 22, 1934. See also Lundmark, *Med. fr. Lund Astr. Obs.*, Series II, No. 60, 1931.

fixed with greater security than heretofore the zero-point of the period-luminosity curve, and in view of the essential clarity of space in high latitudes they have added confidence to our use of cluster variables as accurate indicators of large distances.

We have not as yet sufficient data on the average maximum absolute magnitudes of long-period variables and the dispersion about the mean to make them as useful as cluster variables in distance measurement; and the numerous faint eclipsing stars in galactic latitudes higher than thirty degrees

TABLE I

Variable Stars in High Latitudes

M.W. Field (MWF)	λ	β	Number of Variables		Ecl.	Clus.	Ceph.	Long	Other
			Old	New					
	°	°							
202	45	−20	5	67	24	14	0	18	16
204	135	−20	9	17	6	3	0	5	12
209	0	−40	8	69	19	32	1	5	20
211	170	−40	2	32	10	13	0	3	8
212	270	−40	4	64	17	25	3	6	17
213	0	−60	2	35	12	15	0	5	5
214	95	−60	1	17	2	7	0	1	8
215	180	−60	1	20	8	7	0	1	5
216	270	−60	4	22	2	13	0	5	6
217	180	−80	1	10	1	7	0	1	2
218	356	−80	2	21	5	10	0	4	4
Totals			39	374	106	146	4	54	103

appear to be chiefly doubles of the W Ursæ Majoris type, and therefore impotent in the measurement of the galaxy because of low absolute magnitudes.

For the study of the thickness of the Galaxy we have carried on for several years a systematic photographic programme on the cluster variables in latitudes higher than twenty degrees. Seventy-two fields, well distributed in both galactic hemispheres, were selected about ten years ago.* Each covers approximately eighty square degrees. The photographs have been made with 8-inch and 10-inch telescopes at Bloemfontein, and with 8-inch and 16-inch telescopes at Cambridge and at the Oak Ridge Station. Forty-six of the fields have been examined to date, and for eleven of them (Table I) the study has been sufficient to give periods and light curves for a majority of the variables of all types.† The number of cluster-type variables now

* *Harv. Reprint*, No. 68, p. 86, 1931.

† See *Harv. Bull.*, 877 (1930) and 883 (1931); and *Harv. Ann.*, **90**, No. 4 (in press).

known, outside of the galactic zone $\beta = -20°$ to $\beta = +20°$, is 315, of which 146 have been found as a result of this special programme. In addition, there are 166 cluster variables found in the course of the present survey for which useful magnitudes are not yet available.

Eighteen known cluster-type variables are more than ten thousand parsecs from the Milky Way plane, and two are more than twenty thousand parsecs distant. Many of these remoter cluster variables were found on Harvard plates; the magnitude sequences have been established by the star-count

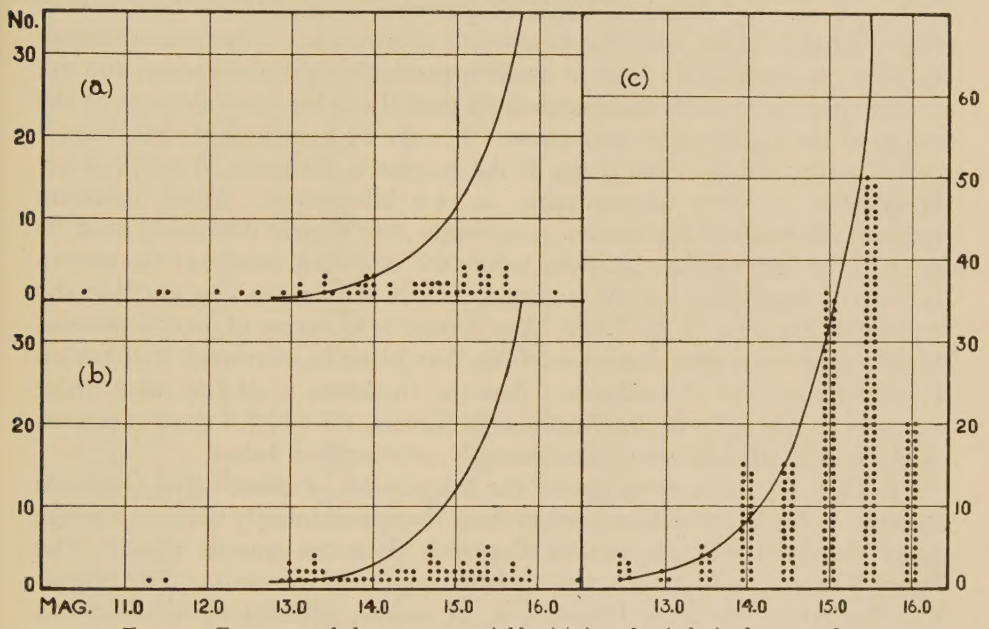


FIG. 1.—*Frequency of cluster type variables* (*a*) *in galactic latitudes* $= 55°$; (*b*) *in latitudes* $-35°$ *to* $-45°$; (*c*) *near the Milky Way plane.*

method, which, in these high galactic latitudes, is essentially reliable, at least to the seventeenth magnitude. For some, Baade has established magnitudes by direct polar comparisons. In setting a lower limit to galactic thickness we should give considerable weight, therefore, to the present observation that there are many cluster-type Cepheids on opposite sides of the galactic plane, separated by distances in excess of 25,000 parsecs. The two most distant on record are in the northern galactic hemisphere—SV Comæ and SX Comæ, at 27·5 and 25·1 kiloparsecs respectively.*

In fig. 1 (*a*) the frequency of the median photographic magnitudes is shown for the 54 cluster variables in the special fields with galactic latitudes $-55°$ to $-90°$. The survey may be taken as complete to magnitude 15, perhaps fainter. The line represents uniform space density, and its poor fit to the observations indicates the considerable galactic concentration of these faint

* Discovered in the vicinity of N.G.C. 4147 by Baade at Bergedorf (*Hamb. Mitt. Berg.*, 7, No. 36, p. 28, 1932). No correction is attempted throughout this section of the paper for possible space absorption.

variable stars. The definite thinning out with distance disposes of the hypothesis which earlier was tentatively held that the cluster-type Cepheids might be intergalactic. The actual distribution, indeed, appears to be comparable with that of the globular star clusters (as Baade has also noted); both show definite affiliation with the Milky Way system, but some individual members, like the cluster N.G.C. 2419,* may indeed be intergalactic.

In fig. 1 (*b*) the frequency of the apparent photographic median magnitudes of 66 cluster-type Cepheids in three fields in the galactic latitude belt $-35°$ to $-45°$ shows, as would be expected, somewhat less falling off in space density fainter than the fourteenth magnitude. These intermediate latitudes are sufficiently high to avoid appreciable light absorption, and yet so low that the variable stars contribute usefully to the measurement of the extent of the Galaxy in its own plane. For the 25 stars with median magnitude fainter than 15·0 the mean of the projected distances, $R \cos \beta$, is 9·7 kiloparsecs, and the largest value is 15·6 kiloparsecs. These numbers indicate the reach of the current programme, but a great deal more must be done in the intermediate latitudes before the minimum extent of the system in various longitudes can be outlined. As it stands, we can say that the equatorial diameter of the Milky Way system is in excess of 30,000 parsecs. Such a great extension along the Milky Way plane is, of course, well known from various lines of evidence; that the thickness is of the same order suggests an analogy with the Andromeda Nebula, for which a great extension of the minor axis has been found recently, as described below.

In fig. 1 (*c*) a frequency plot of the magnitudes of cluster-type Cepheids in seven Milky Way fields is given to show the approximately uniform average space density of the cluster-type Cepheids along the galactic plane. The figure † shows the data grouped in half-magnitude intervals. The magnitude frequency in these latitudes is, of course, affected to an unknown extent by light absorption and structural irregularities, but only those fields were chosen that appear to be essentially clear of obscuring nebulosities.

3. *Galactic Extent in Anti-centre Region.*—The attempt to find the outer limits of the galactic system in the direction of the centre appears futile at present because of light absorption and the great distances involved. Better success should attend attempts at measurement in the anti-centre longitudes, and a special programme on faint cluster-type Cepheids in selected fields is now in progress at the Harvard Observatory. A preliminary survey is shown by the data in Table II, which includes all known ‡ classical and cluster-type Cepheids between galactic longitudes 100° and 200°, and galactic latitudes $\pm 15°$ and $\pm 45°$. Our present uncertainties concerning light absorption in the galactic plane make it of little use to work within fifteen degrees of the galactic circle, and this limitation of course removes from present consideration nearly all of the sixty classical Cepheids known in the anti-centre quadrant. Variables in latitudes higher than 45° also contribute little to our knowledge of the extent of the system in its plane.

* *Cf.* Baade's work reported in *Mt. Wilson Ann. Report*, p. 158, 1932.

† From *Harv. Reprint*, No. 81, 1933.

‡ According to records available up to 1934·0.

TABLE II

Cluster-type and Classical Cepheids in the Anti-centre Region

(Latitudes ± 15° to ± 45°)

Variable	λ	β	$\dot{m}$	R	R'_{ac}
	°	°			
RU Psc	97·5	−38	9·8	1000	400
XX And	96	−23	9·9	1050	400
U Tri	106	−27	12·4	3310	1480
X Ari	137	−39	9·4	830	520
SS Tau	147	−38	12·2	3020	2000
MWF 204, 11	133	−22	11·8	2290	1510
,, 20	137	−25·5	14·2	6920	4700
,, 10	138	−26	14·2	6920	4710
MWF 211, 20	172	−42	14·4	7590	4220
,, 18	171	−41	14·8	9120	5360
TX Tau	137	−18	12·6	3310	2100
MWF 211, 13	174	−40	13·1	4170	2430
,, 46	180	−41	15·8	14300	7800
,, 17	180·5	−41	15·1	10400	5650
,, 19	177	−40	14·0	6310	3590
,, 45	179	−40	15·2	11000	6150
,, 50	179	−40	15·4	12000	6700
,, 52	177	−39	14·8	9120	5250
,, 7	178	−39	14·7	8710	4950
,, 8	179	−39	15·2	11000	6200
SW Tau	157	−30	10·0	1050	710
MWF 211, 34	181	−38	13·8	5760	3210
UX Tau	145	−20	12·0	5760:	3780:
MWF 211, 47	180	−37	15·3	11500	6550
AA Tau	141	−15	14·6	17500:	10670:
SZ Tau	147	−19	7·1	440	290
MWF 258, 8	173	−32	14·0	6310	3980
,, 6	177	−31	12·9	3800	2320
RX Eri	181	−32·5	9·2	690	410
MWF 258, 5	178	−31	13·1	4170	2520
,, 2	176	−28·5	13·2	4370	2720
U Lep	188	−33	9·5	790	420
MWF 205, 12	176	−23	13·7	5500	3380
,, 12*a*	176	−23	13·8	5760	3540
,, 9	179	−21	13·4	4790	2840
,, 5	183	−22	14·0	6310	3620
,, 8	182	−20	14·2	6920	3950
,, 1	182	−20	13·6	5250	2990
RZ Cam	115	+24	12·6	3630	2050
TZ Aur	144	+22	11·6	2290	1550
RR Gem	155	+20	11·2	1910	1280
SZ Gem	169	+22	11·2	1910	1230
VY CMi	184	+17	15·2	22600	12080
SS Cnc	166	+26	12·0	2750	1830
SX Cnc	168	+37	13·0	3980	2480
SZ Hya	207	+26	11·0	1740	650
RW Cnc	165	+43	11·0	1740	1040
UU Hya	198	+38	11·5	2000	870
SU Leo	197	+43	13·1	4170	1760
T Sex	202	+40	9·8	1000	400
V Sex	200	+42	12·8	3630	1450
MWF 214, 6	117	−15	13·7	5500	2860

The galactic co-ordinates are given for each of the variables, also the best value now obtainable for the apparent median photographic magnitude, $\dot{m}$. The values of the distance in parsecs, R, are computed with the aid of the adopted period-luminosity curve * and are uncorrected for light absorption. The last column of the table contains

$$R'_{ac} = R' \cos\beta \cos(\lambda - 150^\circ),$$

where

$$R' = 10^{0.2(\dot{m} - 0.25 \operatorname{cosec}\beta + 5)},$$

and gives the distance for an assumed absorption of light in space that amounts to a quarter of a magnitude (photographic) at the galactic poles and increases with the co-latitude. Values of R'_{ac} show the extent of the system in the direction $\lambda = 150^\circ$, $\beta = 0^\circ$, exactly opposite to the galactic centre.

The value adopted for space absorption is that suggested by Hubble in his study of the distribution of external galaxies.† In the present computation it is assumed that the layer of absorbing material is isotropic and essentially all nearer than the faint variables. The adopted value is probably too large for high latitudes, according to the Harvard studies of the distribution of external galaxies (see section 12 below); it is about three times as large as the Rayleigh-scattering type of obscuration found from studies of the colours of globular clusters by Vyssotsky and Williams.‡

4. *Variable Stars in the Large Magellanic Cloud.*—The fact that the two Magellanic Clouds are within a distance of thirty kiloparsecs gives them peculiar significance in the study of external galaxies. Some of their supergiant members are brighter than the tenth apparent magnitude, and even moderate-sized telescopes effect a complete resolution into stars. The continued study with the telescopes of the Boyden Station emphasizes the general comparability of these nearest of external galaxies with the parts of our own Galaxy that are under closest investigation. The Clouds are therefore ideal for comparative studies of the luminosities of giant and supergiant stars, of the relative frequency of various stellar types, and especially of the many problems of Cepheid variable stars.

To the eight hundred variable stars found in the Large Magellanic Cloud thirty years ago by Miss Leavitt, recent examination of additional plates with the Bruce telescope has added more than six hundred, nearly all of which appear to be of the Cepheid class.§ In advance of the detailed determination of the light curves and periods of the 1346 variables now known in the Cloud, about 20,000 estimates of magnitudes have been made in order to provide for each variable a preliminary value of the median magnitude and the amplitude of variation. The frequency of these median magnitudes is shown as a full line in fig. 2. The maximum probably will be shifted slightly toward fainter magnitudes when the survey for new variables is taken to stars below the limit of the Bruce one-hour exposures; but a maximum very near the sixteenth magnitude will undoubtedly persist.

* *Harv. Mon.*, No. 2, p. 135, 1930.

† *Ap. J.*, 79, 8, 1934; *Mt. Wilson Contr.*, 485, 1934.

‡ *Ap. J.*, 77, 301, 1933.

§ *Harv. Reprint*, No. 101, 1933.

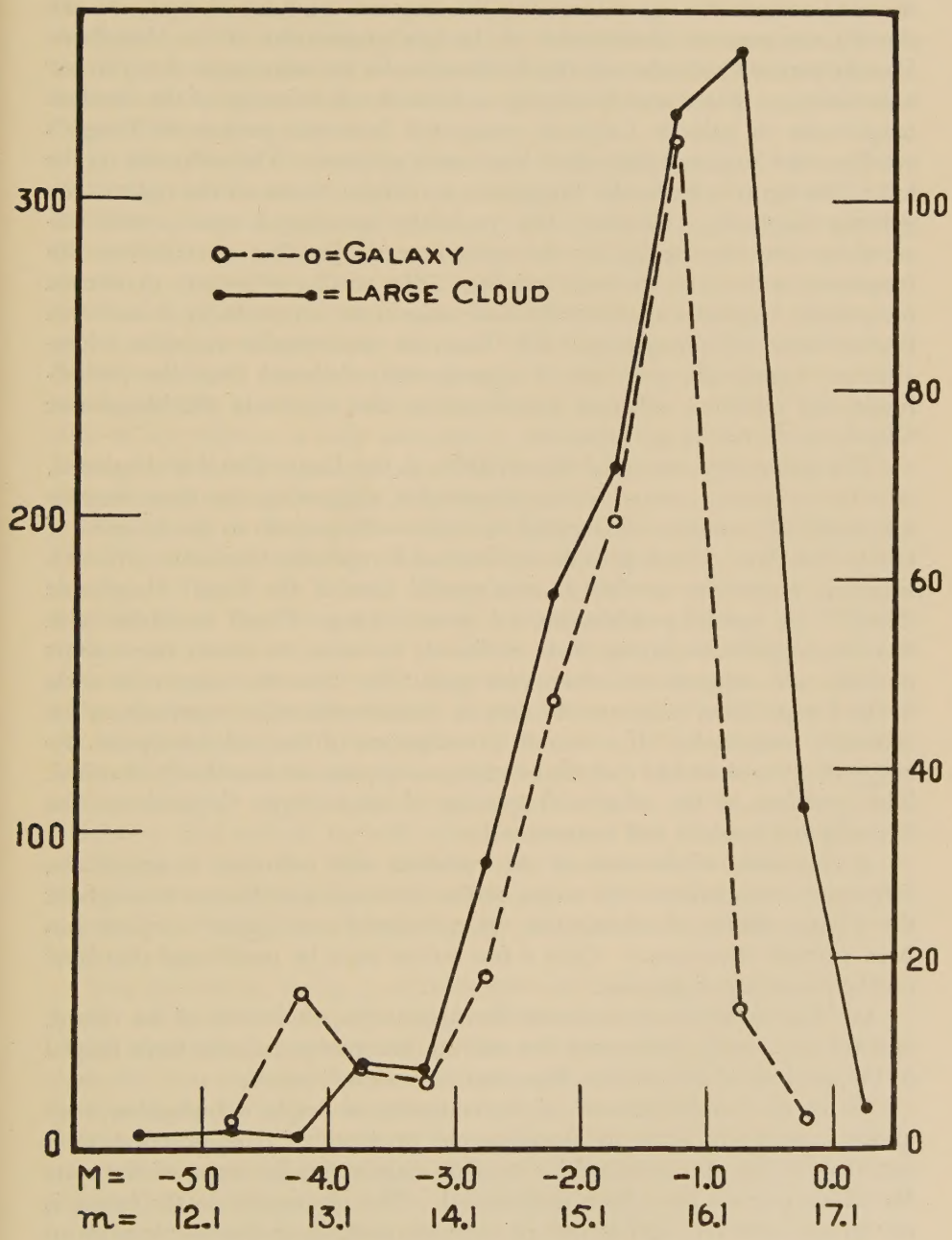


FIG. 2.—*Frequency of galactic and of Large Cloud Cepheids. Ordinates are numbers in the Large Cloud (left) and in the Galaxy (right); abscissæ, computed absolute magnitudes (M) in the Galaxy and apparent magnitudes in the Cloud (m).*

Since the apparent magnitudes in the Cloud can be read directly as absolute magnitudes by subtracting the distance modulus of 17·1, we can directly compare the distribution of absolute magnitudes of the Magellanic Cloud classical Cepheids with the distribution for the same type of star in our own Galaxy. The dotted line in fig. 2 shows the distribution of the absolute magnitudes of galactic Cepheids computed from the periods in Prager's catalogue for 1934 and the period-luminosity relation. The ordinates on the left of the figure refer to the Magellanic variables ; those on the right to the galactic Cepheids. Selection has probably introduced some small uncertainty into the results for the galactic variables, but nevertheless the frequency curves are strikingly similar. The small preliminary maximum for galactic Cepheids at about absolute magnitude -4 probably arises from the inclusion of unrecognized RV Tauri or semi-regular variables whose absolute magnitudes may not be appropriately deduced from the period-luminosity relation ; whether such variation also occurs in the Magellanic Clouds we do not as yet know.

The luminosity curve for the variables in the Large Cloud is displaced, near its maximum, toward fainter magnitudes, suggesting that there may be a considerable number of Cepheid variables with periods in the interval of one to two days. Such periods are unusual for galactic Cepheids, although found in surprising number in one special field of the Small Magellanic Cloud.* A special examination of several Large Cloud variables with median magnitudes fainter than 16 failed, however, to reveal these short periods, and suggests the alternative possibility that the magnitude scale in the Large Cloud is in error by two- or three-tenths of a magnitude at the sixteenth magnitude. If a current investigation of the scales supports the suggestion, we shall find that the two frequency plots are essentially identical. The question of the relative frequency of cluster-type Cepheids in the Magellanic Clouds is still unanswered.

A discussion of the data on the variables with reference to amplitude, frequency, comparison with other stellar systems, distribution throughout the Cloud, effects of obscuration by nebulosity and similar subjects has been printed elsewhere.† Only a few points need be mentioned that bear on the problems of galaxies.

(*a*) The variables are scattered throughout the whole area of the Cloud, and those recently discovered beyond the recognized bounds have helped in the revision of dimensions discussed in section 6 below.

(*b*) In the neighbourhood of the conspicuous bright nebulosities, such as the excessively large 30 Doradus, the presence of dark obscuration is revealed by the abnormally faint median magnitudes for some of the stars for which periods have been determined. The absorption so far found is not great, however, and it can in time be usefully evaluated throughout large sections of the Cloud by the study of the distribution of the more distant faint galaxies that are visible through it.

(*c*) Between one and two per cent. of all the supergiant stars in the Large

* H. B. Sawyer, *Harv. Circ.*, 374, 1932.

† *Harv. Ann.*, 90, No. 1, 1933 ; *Harv. Reprint*, No. 101, 1933.

Cloud between absolute magnitudes −1 and −4 are Cepheid variables; but this proportion varies throughout the Cloud, rising to about four per cent. along the central axis and falling to less than half of one per cent. in the sparsely populated parts of the Cloud. This concentration to more massive regions is analogous to the conspicuous galactic concentration of classical Cepheids in our own system.

5. *The Period-luminosity Curves for the Magellanic Clouds.*—From somewhat insufficient material, the original values of the periods were determined several years ago for forty variable stars in the Large Magellanic Cloud,* and the relation between period and luminosity was found to be essentially the same as that already known from a study of more than a hundred Cepheid variables in the Small Magellanic Cloud.† Since then provisional period-luminosity relations have been determined by the author, Gerasimovič and others for the classical Cepheids in the galactic system, and by Hubble for N.G.C. 6822, Messier 33 and Messier 31.‡ The generality of the relation is fully established, and presumably the relationship is identical when correct magnitude scales and periods are used and appropriate corrections made for local light absorption.

The study of the periods of the variable stars in the Large Magellanic Cloud has been resumed by Miss Hoffleit, from whose unpublished results the data of fig. 3 are taken. The plot includes the periods and median magnitudes of the forty stars studied three years ago, but with slightly revised periods for several of the fifteen reinvestigated. Fifty-eight new periods have been determined. Especial attention was paid to the Cepheids with apparent median magnitudes brighter than 15, in order to strengthen our knowledge of the brighter section of the curve, which is most important in the study of variables in other external galaxies. About twenty per cent. of these brighter variables were examined, but on the plates available it was possible to find periods for only about one out of six, whereas periods were readily found for more than two-thirds of those measured fainter than 15. The difference is probably attributable in part to the presence of a greater proportion of irregular and semi-regular red supergiant variables among the brighter stars.

The distinction, in fig. 3, of three different types of region in the Cloud reveals no systematic trend in the period-luminosity relation dependent on Cloud structure, or any noticeable effect of local obscuration. Stars in the clustered areas are in general nearest to recognized bright and dark nebulosity. As noted in an earlier paper,§ the scattering of the individual values is more pronounced than for the Small Magellanic Cloud. This scattering may be attributed, perhaps, to local obscuration, to errors in magnitudes and periods (least likely), to thickness of the Cloud (which can amount to three- or four-tenths of a magnitude), and to the probable true deviations of the periods or luminosities of Cepheids from average conditions.

* *Harv. Bull.*, 883, 1931. † *Harv. Mon.*, No. 2, 135, 1930.

‡ Gerasimovič, *A.J.*, **41**, 17, 1931; Wilson, *A.J.*, **35**, 35, 1923; Hubble, *Pop. Astr.*, **33**, 252, 1925, and *Mt. Wilson Contr.*, 304 (1925), 310 (1926) and 376 (1929).

§ *Harv. Bull.*, 883, 1931.

The dotted line drawn in fig. 3 is the period-luminosity curve from the Small Magellanic Cloud (co-ordinates are absolute magnitudes and log periods). The deviation from what now seems to be the best smooth curve for the Large Cloud is a matter of some concern. Probably the trouble lies in the apparent magnitude scale for the Large Cloud. A special series of photographs is being made at Bloemfontein to test this hypothesis. Further work is planned also on periods of the brighter Cepheids in the Small Cloud, since the upper part of the curve is now dependent on few points.

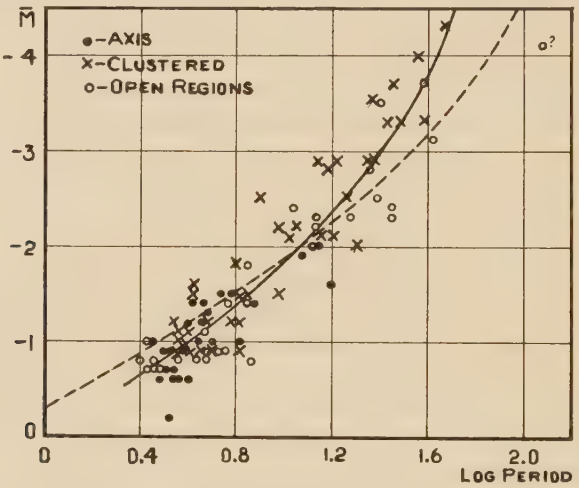


FIG. 3.—*Period-luminosity curve in the Large Magellanic Cloud.*

Awaiting these adjustments, we accept the distance of the Large Cloud as 26·2 kiloparsecs.*

6. *Diameters of the Magellanic Clouds.*—Until recently the angular diameters of the Magellanic Clouds were accepted as 3°·6 and 7°·2 for the Small and the Large Cloud respectively, in full accord with general appearances on the photographic plates. The distribution of variable stars agreed with these values. A careful search of the environs, however, has shown that the Magellanic Clouds, like our own Galaxy in high latitudes, extend in greatly diminished density far from the populous central region. A few outlying classical Cepheids have been found, and doubtless when we reach the cluster-type variables they will be discovered in large numbers in these outer regions. The most definite indication of the greater extent, however, is the number of globular and galactic clusters found by Miss Mohr in the vicinities of both Clouds.† The magnitudes of the globular clusters and the mere existence of the open clusters in such high galactic latitudes assure the proper identification of these objects as Cloud members.

* Application of the general formula in section 3 would change this value to 21·3 kiloparsecs, but such a large general absorption correction must be made with reservation.

† Shapley and Mohr, *Harv. Bull.*, 889 (1932), 895 (1934); and unpublished material on Small Cloud.

That the outlying clusters are not merely detached satellites of the Large Cloud is now demonstrated by series of densitometer tracings on long-exposure photographs, which show a background of stars fainter than magnitude 17 (absolute magnitude zero) extending throughout the area covered by the clusters. In fact, counts of stars on long-exposure plates have verified the densitometer result for the Large Magellanic Cloud, and it appears likely that when the analysis is carried to magnitude 20 there will be found a relatively dense population of main sequence stars which are inconspicuous only in contrast to the high concentration of supergiants that make up the central body of the system.

A densitometer tracing from plate AX 1949 (1 mm. = 700″, exposure 90 minutes) is reproduced in fig. 4 to show that the earlier diameter of the Small Magellanic Cloud is more than doubled. We accept at present

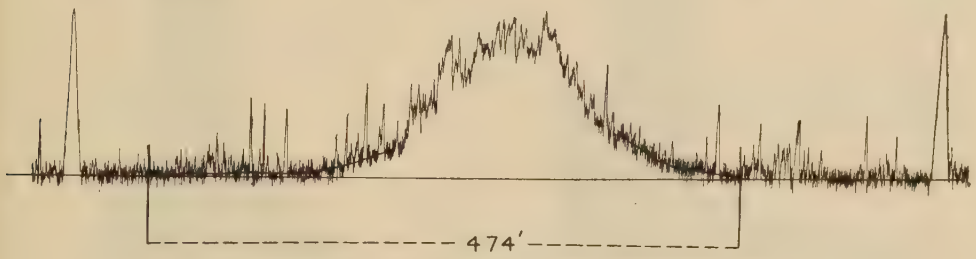


Fig. 4.—*Densitometer tracing across the Small Magellanic Cloud.*

angular diameters of eight degrees and twelve degrees for the Small and the Large Magellanic Cloud respectively, corresponding to linear diameters of 4 and 5·5 kiloparsecs.

7. *Spectra of the Magellanic Supergiants.*—In fig. 5 is shown the distribution among the various spectral classes of the spectra of approximately three thousand stars in and in front of the Large Magellanic Cloud, as well as similar results for a nearby comparison field with the same total population in classifiable spectra. Differences in distribution are obvious and important. Except for Class O stars, few objects fainter than magnitude 13 have been classified ; we therefore deal chiefly with the foreground of the Cloud, since only its supergiants of absolute photographic magnitude −4·0 and brighter appear in this spectrum survey. The new spectral classifications will be published by Miss Cannon in the Henry Draper Extension,* together with photographic magnitudes.

The comparison star field, in right ascension $5^h\ 10^m$, declination $-45°$, is in the same galactic latitude as the Cloud, and the centres of the two fields are twenty-five degrees apart. It is noteworthy that only stars from Classes A to M inclusive appear in the control field. All the planetaries and the B, O, P Cygni, and variable stars, and perhaps also one-half of the A and M and some of the K stars in the Cloud field, are actual supergiant members of the external galaxy. For those stars brighter than the tenth magnitude we shall soon discriminate between foreground and Cloud with the aid of a small

* *Harv. Ann.*, **100.**

dispersion spectrograph used with the 60-inch reflector at Bloemfontein, since the radial velocity of +275 kilometres a second for the Cloud should immediately sort out its members.

Many of the Class B stars are brighter than apparent magnitude 10; they are therefore more luminous than the average nova at maximum, and

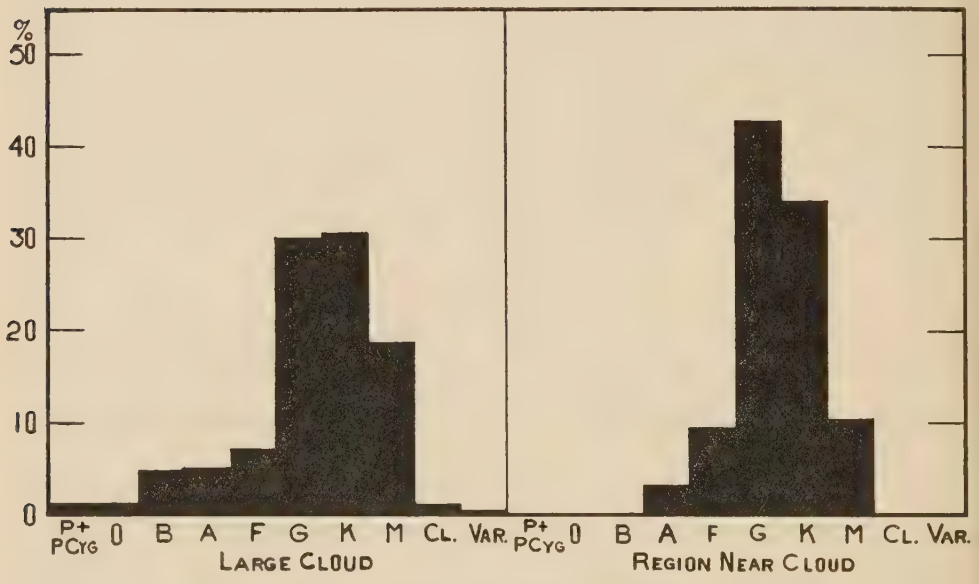


FIG. 5.—*Distribution of spectral classes in the Large Magellanic Cloud and in a neighbouring comparison field.*

they are, as constant sources of radiation, the most astonishing single bodies known.

8. *Dimensions of the Andromeda Spiral.*—The extension, through the study of clusters and special types of stars, of the recognized dimensions of our own Galaxy in high latitudes and of both the Magellanic Clouds directs attention again to the actual form and dimensions of spiral galaxies. The Andromeda Nebula, for instance, has been generally accepted as an elliptical system with axes of 160′ and 40′ at the most, as determined on long-exposure photographs with the larger reflecting telescopes.* The removal two years ago of the Harvard patrol cameras to the favourable Oak Ridge location has permitted long exposures that, upon direct visual inspection, indicate dimensions considerably larger than those shown on reflector plates. Densitometer tracings, one of which is reproduced in fig. 6, verify the great extension of the system.† Plates were made with various cameras, with apertures from 1·5 to 4 inches, and focal ratios from 4·0 to 7·0. A length of 4°·5 and a width of 4° are indicated by the densitometer measures, and still more suitable technique will probably increase both these values slightly.

* Hubble uses 160′ for the major axis; Lundmark uses 150′ (*M.N.*, **85**, 885, 1925).

† *Harv. Bull.*, 895, 1934. See also Stebbins and Whitford, *Pub. Nat. Acad. Sci.*, **20**, 93, 1934.

The corresponding linear dimensions are 19·4 and 17·1 kiloparsecs. The total area covered by the system is ten times that covered by the familiar central portion ; in fact, the nebula in projection would spread over one-third of the bowl of the Big Dipper.

If further study establishes the approximate ratio of major and minor axes as given above, we have in the Andromeda Nebula, and perhaps in our own Galaxy as well, an interesting new feature of galactic structure—a highly flattened discoidal mass with an essentially spherical low-density envelope, possibly composed chiefly of special types of objects.

In 1932 Hubble published positions and magnitudes for 140 objects in and on the borders of the Andromeda Nebula, which he provisionally

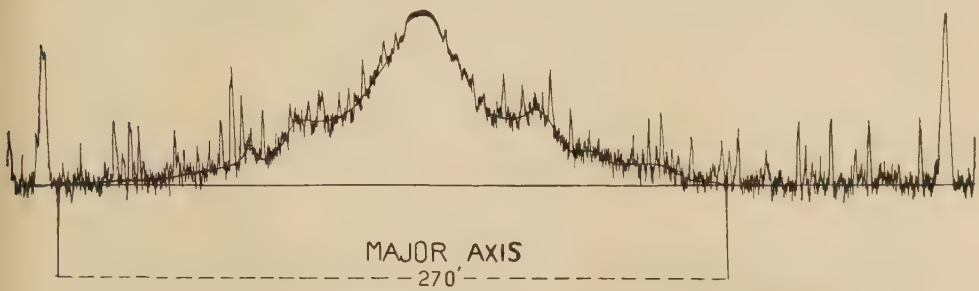


Fig. 6.—*Densitometer tracing of the Andromeda Nebula.*

identified as globular clusters.* Miss Mohr's work on the Magellanic Clouds suggests that many of these objects should probably be classed as open clusters ; but in any case their distribution appears to affiliate them definitely with the Andromeda Nebula. Their area of distribution is but a fourth of that now shown for faint stars by the densitometer, since all but a few of the clusters are within 60′ of the nucleus, and the most remote is 80′ distant. The greater distances surmised by Hubble arose through his multiplication of one co-ordinate by four on the natural assumption that the clusters are in or near the plane of the nebula. That assumption no longer seems necessary in view of the distribution of faint stars. A search for additional clusters in the nebula's high galactic latitudes should be profitable.†

Both of the companions of the Andromeda Nebula lie within the enlarged major system, at least well within the area of the projection. We already have the analogous indication that our galactic system's membership of cluster-type Cepheids may reach beyond the Magellanic Clouds.

It is a reasonable speculation that the outlying haze of stars in the Andromeda system may include cluster-type variables, and it only awaits our ability to photograph appropriately the stars of magnitude 22 for the testing of this suggestion and for the quick sorting out of the individual Andromedan stars remote from the central nucleus.

* *Mt. Wilson Contr.*, 452, 1934.

† A score of suspects have already been marked in these regions on a long-exposure plate recently made at Oak Ridge. This plate and a Bruce plate show also an outlying irregular patch of nebulosity (magnitude 15) on the major axis 1°·6 from the nucleus!

9. *Densitometer Measures of Bright Galaxies.*—To extend further the examination of the outer regions of the nearby galaxies, densitometer tracings have now been made for sixty-six systems. The results are summarized in Table III for the twenty-one for which the diameters based on reflector plates have also been published by Hubble.* The Harvard values are based in part on the original negatives and in part on glass positives, as indicated

TABLE III

Diameters of Galaxies

N.G.C.	Class	Magnitude	Diameter (*Mt. W. Contr.*, 324)	Densitometer Diameter	Dens./Mt. W.	Type of Plate
			′	′		
253	S*c*	7·0:	22·0	30·0	1·4	B *n*
2976	S*c*	11·2	3·2	7·6	2·4	MC *p*
3031	S*b*	8·9	16·0	24·8	1·5	MC *p*
3034	I	9·4	7·0	14·0	2·0	MC *p*
3077	I	11·4	3·0	10·4	3·5	MC *p*
4371	SB*a*	12·1	1·5	6·2	4·1	A *n*
4429	S*a*	11·7	3·0	9·9	3·3	A *n*
4442	SB*a*	11·4	3·2	7·4	2·3	A *n*
4472	E	10·1	2·0	16·3	8·2	A *n*
4486	E	10·7	2·0	11·5	5·8	MC *n*
4517	S*c*	11·6	10·0	11·9	1·2	A *p*
4526	S*a*	10·7	5·0	10·8	2·2	A *n*
4536	S*c*	11·2	7·1	5·4	0·8	A *p*
4570	E	12·0	2·4	6·0	2·5	A *n*
4579	SB*c*	11·0	2·8	10·3	3·7	MC *n*
4632	S*c*	12·1	3·2	4·2	1·3	A *p*
4636	E	10·8	1·2	6·9	5·7	A *p*
4643	SB*a*	11·6	1·8	4·6	2·6	A *p*
4649	E	10·6	2·0	10·2	5·1	MC *n*
4665	S*a*	11·8	1·2	4·6	3·8	A *p*
4666	S*c*	11·3	4·0	6·0	1·5	A *p*

in column 7. The Bruce plates are too large for direct densitometer work. A new instrument is under construction with which an extended programme will be undertaken on the dimensions of external galaxies, and on the relative intensities throughout their outer portions.

The total magnitudes in the third column of the table are taken from *Harvard Annals*, **88**, No. 2, and the classes are in general those given by Hubble. The letters A, MC and B in column 7 refer to the Bruce 24-inch, the Metcalf 16-inch and the Bache 8-inch telescopes. It is seen that these moderate-sized refractors, like the small patrol cameras, are well adapted to

* *Mt. Wilson Contr.*, 324, 1926. It should be noted that Hubble (*Mt. Wilson Contr.*, 398, 1930), and Carroll and Moss (*M.N.*, **91**, 199, 1930), have also found that densitometer measures extend the diameters, especially of the spheroidal galaxies, over those obtained by visual inspection of the photographs.

the study of the faint envelopes of external galaxies. For the five spheroidal systems listed in Table III the diameters average 5·5 times the values heretofore published ; for the spirals, the increase is about 2·3 times.

A striking example of the densitometer enlargement of a spheroidal system is shown in fig. 7, where a tracing is reproduced of the well-known double, Messier 60 (spheroidal), and its spiral companion, N.G.C. 4647. The centres are 2′·5 apart, and their edges usually appear well separated on ordinary photographs. The tracing from a three-hour Bruce photograph shows, however, that the companion is well inside the recorded bounds of Messier 60, for which the total diameter is ten minutes of arc, corresponding

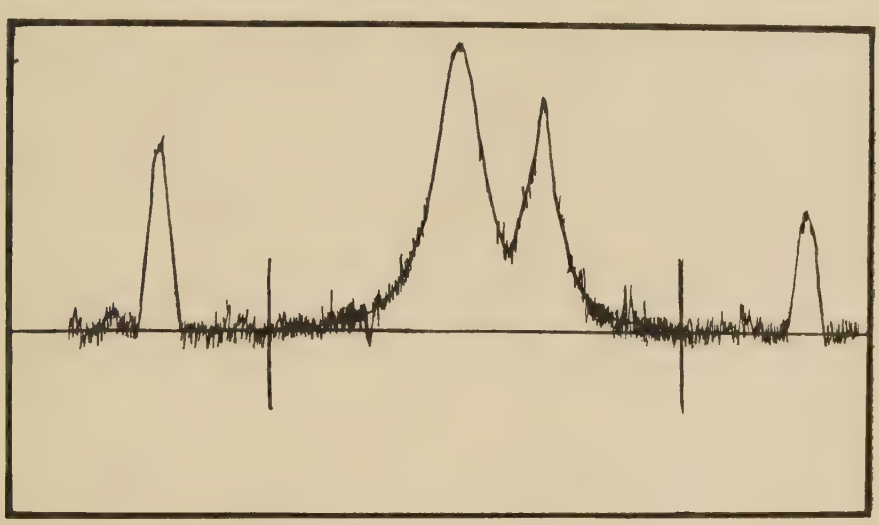


Fig. 7.—*Densitometer tracing across Messier* 60 (*N.G.C.* 4649) *and N.G.C.* 4647, *on a Bruce three-hour plate.*

approximately to nine thousand parsecs. The companion also encloses Messier 60, and the two may in a sense be considered large, massive nuclei in a tenuous envelope of scattered stars.

10. *Relative Dimensions of Spheroidal and Spiral Galaxies.*—Two results cited above, namely, the relatively great extension of Messier 60 and the much larger increase of measured diameter for spheroidal than for spiral systems (Table III), raise the question of the relative sizes of spheroidal and spiral galaxies—a question important in seeking a dynamical interpretation of spiral arms. The data heretofore available have indicated that spirals are from two to three times the dimensions of spheroidal systems, which they also exceed in number, at least among brighter galaxies, by more than two to one. Adequate material for the examination of the relative dimensions is now available from long-exposure Bruce photographs. For 488 objects brighter than magnitude 13 direct measures have been made on the negatives with scale and low-power eye-piece. The classification is definite for 451, of which 319 are spirals. For all spheroidal systems, and all but one of the spirals that are also measured on reflector plates, these new measures give

larger dimensions.* The difference between the new and the earlier values increases with the diameter ; on the average the ratio of the Harvard to the Mount Wilson † measures is 3·2 for the spheroidal systems and 1·6 for spirals. Subsequent densitometer measures of these bright galaxies will probably increase the dimensions by at least thirty per cent. on the average —more for the spheroidal than for the spiral systems (see Table III above) ; but as they stand the visual measures suffice for the present purpose of intercomparing spheroidal and spiral nebulæ. For the whole of the new material (451 objects) the ratio of the diameters,

$$S/E = 1{\cdot}7,$$

gives only the relation, in the magnitude interval 10 to 13, of apparent dimensions of spiral to spheroidal systems ; the ratio of linear dimensions cannot yet be readily deduced because of too little knowledge of the average absolute magnitudes of the two types and therefore of their average distances. Preliminary information on intrinsic luminosities would indicate brighter average absolute magnitudes for the spheroidal systems, therefore greater average distances, with consequent reduction of the above ratio.

Fortunately, in this new survey of diameters nearly a hundred of the members of the great Virgo supergalaxy appear. Ignoring, appropriately, their differences in distances, we get from them the following comparison of angular diameters, which we may take also as the best value now obtainable of the relative dimensions of spiral and spheroidal systems :—

Spiral, mean diameter . . .	4′·8 (54 objects)
Spheroidal, mean diameter . . .	3·9 (30 objects)
Ratio . .	1·23

As mentioned above, densitometer work will reduce this ratio considerably, and we therefore conclude that spiral and spheroidal galaxies as now photographed are, on the average, of equal dimensions.

Subdividing the list of spiral nebulæ in the preceding tabulation, we find the diameters as follows :—

S	4′·2 (19 objects)	SB	2′·5 (1 object)
S*a*	4·4 (12 ,,)	SB*a*	3·9 (4 objects)
S*b*	6·2 (5 ,,)	SB*b*	4·3 (3 ,,)
S*c*	6·0 (8 ,,)	SB*c*	7·3 (2 ,,)

For the spheroidal systems, a progression in average size with decreasing ellipticity is shown :

$a \geqslant 2{\cdot}5\ b$	2′·4 ± 0·3 m.e. (6 objects)
$1{\cdot}5\ b < a < 2{\cdot}5\ b$ . . .	3·6 ± 0·8 m.e. (7 ,,)
$a < 1{\cdot}5\ b$	4·6 ± 0·7 m.e. (17 ,,)
All	3·9 ± 0·4 m.e. (30 ,,)

* See fig. 2, p. 102, of *Harv. Ann.*, 88, No. 4, 1934.

† Hubble, *Mt. Wilson Contr.*, 324, 1926.

The trend is opposite to that deduced by Hubble, who found the major axes of the longest ellipsoidal systems more than three times the diameters of the circular systems, but his result refers chiefly to what we would here consider the nuclei of the galaxies. The average major axis of spheroidal systems, according to the above measures, is

$$3200 \sin 3'\cdot 9 = 3\cdot 7 \text{ kiloparsecs},$$

whereas Hubble's values range from 0·36 kiloparsecs for the circular class, Eo, to 1·13 for E7.*

11. *Surveys in the Metagalactic System.*—In addition to the Lund General Catalogue of Nebulæ, under the direction of Dr. Lundmark,† there are five comprehensive surveys which should be mentioned in considering the progress of our knowledge concerning the structure of the Metagalaxy. They are presented in the order of increasing depth.

(*a*) The Harvard census of galaxies brighter than magnitude 13 ‡ has provided a working photometric catalogue of 1249 of the brightest systems. The published distribution charts show well-known characteristics: (i) the greater richness of galaxies in the northern hemisphere; (ii) the conspicuous irregularity in distribution in both hemispheres; (iii) the three to one ratio of objects showing spiral structure to objects of all other types.

The total photographic magnitudes of these brighter objects were determined, with reference to stellar standards, on small scale plates, using chiefly focal images and direct estimates. Provisional extra-focal estimates and measures with the Schilt microphotometer seem to indicate fair accuracy in the resulting nebular magnitude scale throughout the interval of brightness here involved. The essential correctness of these total magnitudes is important for estimates of distance, dimensions, space absorption and colour indices throughout the Metagalaxy, and at Harvard, Yerkes and other observatories investigations of the magnitude scale are in progress. Dr. Whipple at Harvard is measuring the colours of many of these brighter objects. The angular diameters, on long-exposure plates, for forty per cent. of them have been published.§

(*b*) A co-operative survey of individual bright nebulæ with telescopes of 24 inches aperture or larger is in progress under the auspices of Commission 28 of the International Astronomical Union, following a plan detailed by Hubble in 1925. Most of the northern sky has been assigned to co-operating observatories. For various reasons the progress has been slow, especially in the southern hemisphere, but there the Harvard thirteenth magnitude survey and the comprehensive long-exposure programme, mentioned in subsection *d* below, practically meet the requirements. It is proposed for each of the two thousand or so brightest nebulæ to get somewhat detailed information as to type, orientation and character of the nucleus, ultimately collecting the results for publication in a fully illustrated catalogue.

* *Mt. Wilson Contr.*, 324, p. 42, 1926.
† *Lund. Medd.*, No. 120, 1930; *Trans. I.A.U.*, 4, 172, 1932.
‡ *Harv. Ann.*, 88, No. 2, 1932.
§ See section 10 above.

(*c*) A uniform photometry for the whole sky of the galaxies between magnitudes 13·0 and 15·0 has just this year got under way at the Boyden and Oak Ridge stations of the Harvard Observatory. It is intended in this way to connect the bright nebula survey with the long-exposure programme with the larger Harvard refractors. Something like fifteen thousand systems will be involved, and the problem is first attacked through the photometry of twelve large selected areas, covering a total of 2500 square degrees. Three cameras equipped with Ross lenses will provide the material for the magnitude measurement in a Schilt microphotometer; photographs with larger instruments will provide for identification and classification. When all external systems to the fifteenth magnitude are described and measured on a fairly homogeneous system, we should be able to discern with some clarity the structure of the inner Metagalaxy.

(*d*) The "eighteenth magnitude survey" was begun actively with the Bruce telescope nearly ten years ago, when there was already an important collection of earlier long-exposure photographs of southern nebulæ. The plan is to cover the whole sky south of declination $+25°$ with three-hour exposures on fast Bruce plates. About two-thirds of the southern hemisphere has been completed. The plates, on the average, show stars a little fainter than the eighteenth magnitude, and are essentially complete for the nebulæ to 17·5. A chart (Aitoff equal-area projection) showing the regions now covered appears in fig. 8.

Recently the 16-inch Metcalf telescope at the Oak Ridge station has begun systematic three-hour exposures on the northern sky. The progress of this survey is indicated in the northern declinations of fig. 8. The sky is also being covered with shorter exposures, thirty minutes to one hour, with the same two instruments, and the short-exposure programme is now more than two-thirds completed.

The examination of the long-exposure photographs lags only a little behind the making of the plates, but the extensive labour of measuring magnitudes, diameters and positions, and making classifications, must fall far behind. In the course of the survey 125,000 new galaxies have been found to date. Of these, less than four thousand have been published in detail, but the work has been completed on twelve thousand objects, new and old, in three sections of the sky, as follows :—

Region	Centre	Area Square Degrees	No. Nebulæ		Publication
			Known	New	
	h m °				
α	12 25 +12·5	131	622	2156	A. Ames, *Harv. Ann.*, **88**, No. 1.
β	3 20 −26	134	60	925	R. Baker, ,, ,, **88**, No. 3.
γ	3 45 −52·5	174	224	8000 ±	Unpublished.

The magnitudes are determined by direct comparison with stellar sequences, a procedure that succeeds fairly well, to the accuracy sought, for objects

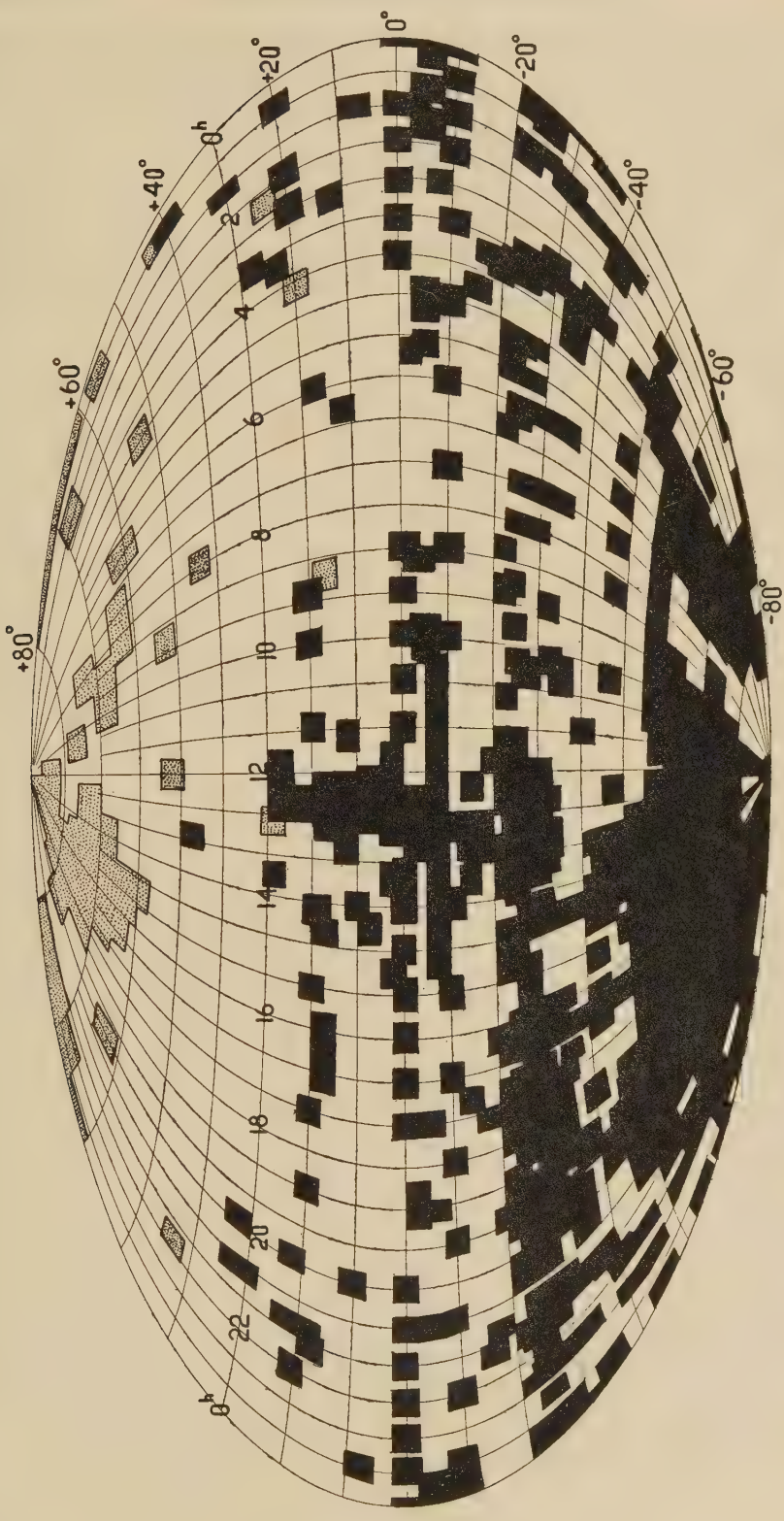


FIG. 8.—*Regions of sky covered by Harvard surveys with 24-inch Bruce and 16-inch Metcalf telescopes. Equatorial co-ordinates are indicated.*

between the sixteenth and eighteenth magnitudes, but is very uncertain on these long-exposure plates for objects brighter than magnitude 15. In general, an attempt is made to measure all these brighter objects on plates of smaller scale and shorter exposure.

The data for the twelve thousand galaxies for which complete measurements are available show, among other things, the usual irregularity in distribution on the surface of the sky, and also the irregular density in the line of sight that is inferred from the diversity in the magnitude frequency curves from place to place. From the correlation between the angular diameters and apparent magnitudes it appears that there is no conspicuous light absorption in high galactic latitudes, but limitations inherent in the photography of faint centrally concentrated nebulæ tend to make this test for space transparency not too convincing.* It is also found, as Hubble has shown, that when very large areas of the sky are considered and deep distances are involved the number of systems increases, on the average, about fourfold per magnitude, thus indicating no appreciable falling off in mean space density with distance.

(*e*) The metagalactic survey that goes deepest into space is that recently completed by Hubble at Mount Wilson.† In each of 1283 small selected areas well distributed over the sky north of declination $-30°$ it accounts for the nebulæ to photographic magnitudes between 19 and 20. This survey very clearly marks out the Milky Way "zone of avoidance" throughout three-fourths of its course. The zone has been generally known since the time of the Herschels, but Hubble's work is the first to give a good preliminary idea of the borders of complete and of partial obscuration.

In all places where they touch problems in common the Mount Wilson and Harvard metagalactic surveys of faint galaxies are in good accord.

12. *Distribution of Galaxies with Respect to Latitude.*—The count of the total number of galaxies for all the sky that has now been covered adequately provides a test of the dependence of number on galactic latitude. To gain homogeneity, only data from the central nine square degrees of the long-exposure Bruce plates have been used in this investigation, and therefore the plot in fig. 9 is based directly on but twenty-eight thousand objects. The average number per square degree is plotted for ten-degree intervals of latitude. The dots and full curve represent the material as it comes directly from the plates ; the crosses and broken line show these same results reduced to a common plate limit as determined by star counts and the Seares and van Rhijn tables.‡ It appears that the density per square degree is independent of the latitude from $+25°$ to the north galactic pole, and also varies with latitude little, if at all, in the southern galactic hemisphere from $-30°$ to $-90°$.

From his own data, based on the selected areas photographed with the Mount Wilson reflectors, Hubble infers a dependence of average number on galactic latitude throughout each hemisphere. An examination of his published results, however, especially for the regular survey fields, shows

* *Harv. Bull.*, 864, 1929. † *Mt. Wilson Contr.*, 485, 1934.

‡ *Proc. Nat. Acad. Sci.*, **19**, 389, 1933 ; *Harv. Reprint*, No. 90, 1933.

very close agreement with the Harvard results, even to the detail of giving some evidence of change in density with latitude in the southern polar cap and practically none at all in the north above galactic latitude $+30°$.*

13. *Concerning a Metagalactic Density Gradient.*—The thirteenth magnitude survey emphasizes quantitatively the long known qualitative observation that the northern galactic hemisphere is richer than the southern. Preliminary studies of fainter galaxies seemed further to support the view of a fundamentally richer northern sky. The question has been raised, especially by van de Kamp,† as to whether the one-sidedness could not be accounted

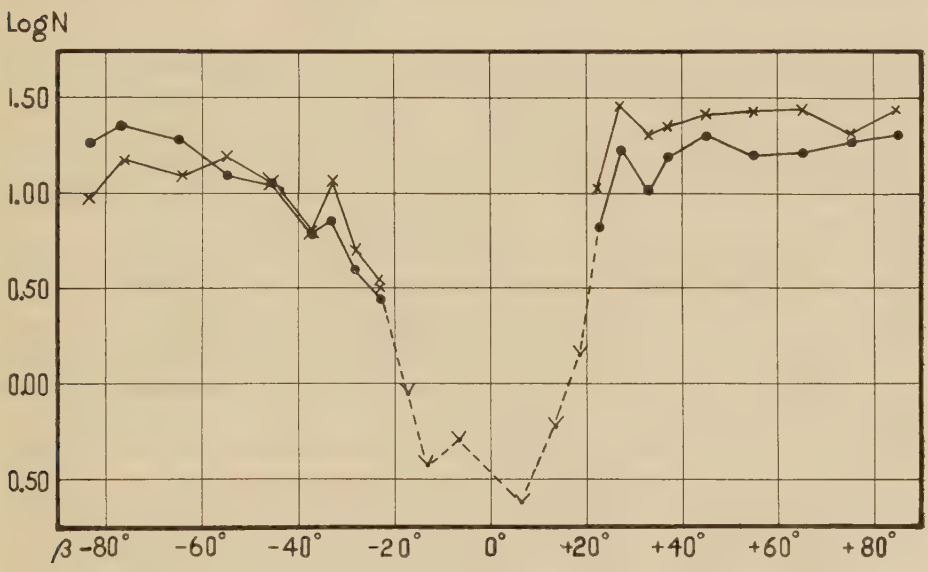


Fig. 9.—*Number of galaxies per square degree, for different galactic latitudes.*

for by absorption in the Milky Way. Apparently, however, this explanation does not suffice, since, in the first place, it does not account for the great irregularities of density from one part to another of a galactic polar zone, and, in the second place, Hubble's total numbers of nebulæ to magnitude 19·5 or fainter are essentially the same for both hemispheres. That absorption within the galactic system cannot account for irregularities in the distribution of the nebulæ has been shown by a special examination of the distribution of faint stars in regions rich and poor in nebulæ ‡; and that the irregularities in the distribution of the nearer nebulæ cannot be caused by obscuration within or outside the region of galactic stars has been shown by Bok,§ who demonstrates that the irregularities in distribution for the nearby and the remotest known nebulæ are not correlated.

To test further the unequal population of the two hemispheres, a special study has been made of the magnitudes of ten thousand systems in galactic latitudes higher than $\pm 40°$, and in declinations between $+22°$ and $-20°$.

* *Mt. Wilson Contr.*, 452, Table XI; *Harv. Bull.*, 894, p. 10, Table III.
† *A.J.*, 42, 97, 1932. ‡ *Harv. Bull.*, 890, 1932. § *Ibid.*, 895, 1934.

The details of this investigation have recently been published,* and only one conclusion need be cited here. The ratio of the number of nebulæ per square degree in the north to the number per square degree in the south for different magnitudes or magnitude intervals is as follows :—

Magnitude :	12–13	14–18	16·0	17·0	17·6	19–20
N_n/N_s :	1·6	1·4	1·25	1·5	1·1	1·0

The last entry is based on Mount Wilson data. The first entry refers to the whole of each hemisphere, whereas the rest of the data are derived from the equatorial zone alone.

It appears that a real excess exists in the north, but that the balance is restored when we reach the eighteenth magnitude and distances of the order of a hundred million light years. A very extensive cloud of faint galaxies, at distances between thirty and a hundred million light years, appears to contribute heavily to the inequality between the two hemispheres, in much the same manner as the canopy of bright galaxies through Virgo, Coma and Ursa Major contributes to the un-balance of the inner Metagalaxy.

In the Harvard eighteenth magnitude survey we have recognized three or four other metagalactic clouds whose diameters and population are of an order higher than that of the ordinary group or cluster of galaxies. Bernheimer † has commented on a series of groups and clusters of galaxies which may perhaps be comparable to this northern metagalactic cloud that appears to produce a distinct density gradient throughout the region now under survey.

14. *Groups and Clusters of Galaxies.*—One out of every twenty-five galaxies on the long-exposure Harvard plates is a component of a double, according to a summary of distributional data for forty-three thousand objects. A double is defined as a pair whose separation at nearest edges does not exceed the diameter of either ; but objects with great difference in total magnitude are not admitted. Even with the appropriate correction for "optical doubling," the physical association of galaxies is found to be very common. Multiple systems are not rare, and groups and clusters of individual galaxies throughout the Metagalaxy appear to be analogous in nature and frequency to the grouping and clustering of stars in the galactic system. As for the open star clusters of the Milky Way, so also for loose groupings among the galaxies, no sharp line can be drawn between irregularities in distribution and coarse clustering. Lundmark speaks of hundreds of recognized "metagalactic clusters," whereas Hubble lists but a few rich objects as clusters of galaxies.

The clusters of galaxies can play the same important part in studies of total luminosities of individual members and in estimates of distance as the clusters of stars play in the investigation of the galactic system. We have therefore paid special attention at Harvard to the groups of galaxies, and especially to the determination of luminosity curves, in the hope of providing data for the measurement of distance. Accepting first only the richer systems, we have determined magnitudes in about thirty groups. In general,

* *Harv. Bull.*, 894, 1934. † *Nature*, **130**, 132, 1932.

because of plate limitations, only the most luminous objects in the groups can be reached. A similarity of the average linear diameters of the brightest members in each group has been found, and this similarity may eventually be useful as a distance criterion. If our estimates of the distances are approximately correct, the average density of matter within the groups can be expressed as of the order of 10^{-70} galaxies per cubic centimetre. In practically all of the thirty groups the density is more than a hundred times the density outside.

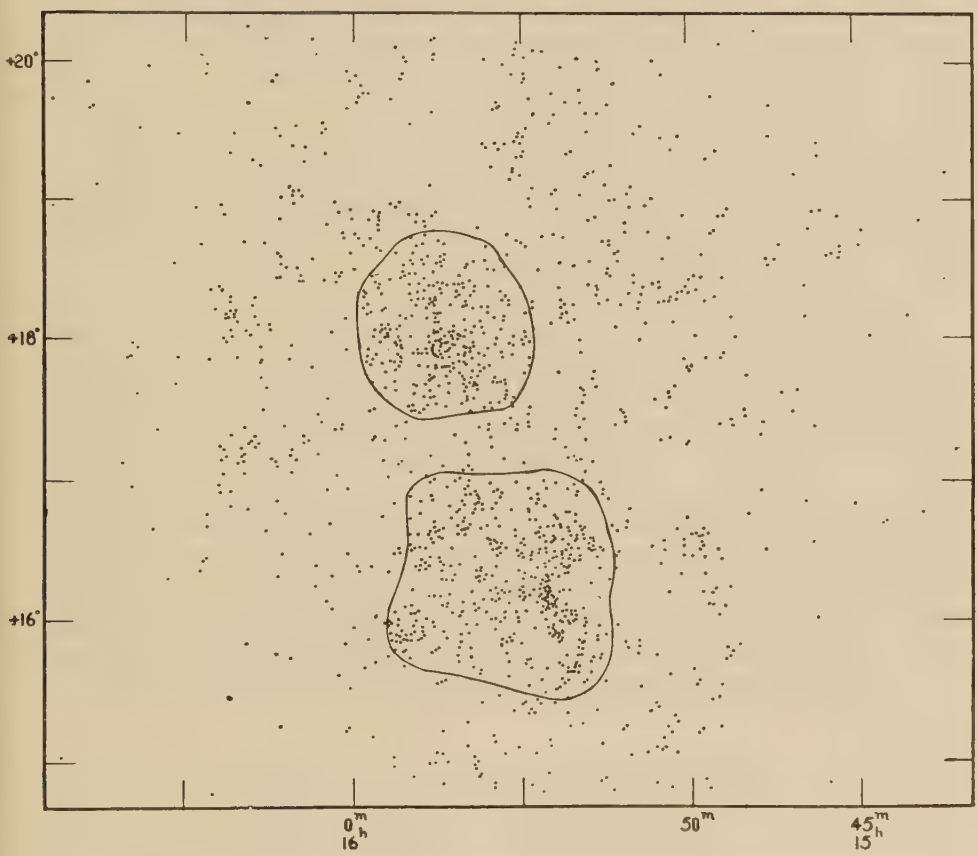


FIG. 10.—*Distribution of members of the double supergalaxy in Hercules (Equinox 1935).*

A special study has been made of the structure of Wolf's rich cluster of faint nebulæ in Coma (R.A. $12^h\ 55^m.8$, Dec. $+28°\ 18'.3$). The central part of this group has also been studied at Mount Wilson. With proper allowances for the limiting magnitudes of the plates involved and for the relative areas surveyed, the luminosity curves are in good agreement.* The magnitudes, although determined by quite different methods, agree in showing the maximum frequency at about magnitude 16·7 (corrected for red shift), and if we adopt -14.5 as the corresponding absolute magnitude, we deduce a distance of 17·4 megaparsecs. Throughout an area with a radius

* See *Harv. Bull.*, 896, 9, 1934.

of 250 kiloparsecs the population is about 500 galaxies. If we accept provisionally 10^9 solar masses as the mass of an average galaxy, we find that the density of matter in space throughout the Coma group is of the order of 10^{-27} grams per cubic centimetre, in agreement with the result referred to above for thirty groups.

Undoubtedly the most important of the clusters of galaxies now known is the supergalaxy in Virgo. Its significance arises from the circumstances that it is probably not much more than three megaparsecs distant, that its radial velocities can be studied in detail, that some of its members are partially resolved with large reflectors, and that the comparative anatomy of physically related galaxies can be investigated minutely. If it were not for its great distance (perhaps thirty megaparsecs or more) the twin supergalaxy in Hercules, the distribution of whose brighter members is shown in fig. 10, would be equally interesting. Future studies of this region of the sky may show that in fainter members the twins are one, and show also that they are but concentrations in an exceedingly rich region, a metagalactic cloud of the type referred to in the preceding section.

The foregoing account of results obtained and work in progress in the fields of galactic and metagalactic exploration and measurement shows that, in spite of the magnitude of the subject, a large number of problems are open to successful investigation. The progress of the work at Harvard will continue to depend on the co-operative efforts of many members of the observatory staff. To these colleagues I am deeply indebted for assistance with the details of the various researches; only partial acknowledgment could be made in the foregoing report. I am especially indebted to Miss Mohr for her assistance in all phases of the work and in the preparation of this account; and I am under great obligation to Dr. Paraskévopoulos and the members of his staff at the Boyden Station for their steadfast efforts in carrying forward numerous exacting programmes on variable stars and galaxies.

1934 *September* 8.

THE SPECTRUM OF NOVA RR PICTORIS IN 1934.

H. Spencer Jones, F.R.S., Astronomer Royal.

The continued slow decline in the brightness of Nova RR Pictoris has made it possible for photographs of the spectrum to be obtained again this year by Mr. Worssell with the objective-prism attached to the Franklin-Adams telescope at the Union Observatory, Johannesburg. Mr. Worssell kindly obtained one spectrogram with a total exposure of 11 h. 20 m. between February 11 and 16, and a second spectrogram with a total exposure of 14 h. 5 m. between March 16 and 20. Imperial S.S. plates were used, bathed in a bath containing sensitol green, sensitol red and sensitol violet;

only two-thirds of the usual amount of ammonia was used for the second plate. The first plate is poor and badly fogged, but the second plate is much better. Mr. Worssell suggests that the improvement in the second plate might be due to the lessened amount of ammonia in the sensitising bath, though previous experiments in this direction had given no improvement in the fogging tendencies of the plates and a slightly decreased sensitivity : he considers it possible that the decreased amount of ammonia may be an improvement when the plates are exposed to the air for several days. The focus, especially at the blue end of the spectrum, is not so good as usual, due partly to temperature changes. I am much indebted to the Union Astronomer, Mr. Wood, for arranging for these spectra to be obtained.

I have received also from Dr. Paraskévopoulos, Director of the Boyden Station of Harvard Observatory, Bloemfontein, South Africa, contact positives from two photographs of the spectrum of the nova obtained with an objective-prism attached to the 13-inch Boyden telescope. One photograph was obtained on February 5–6, with an exposure of 90 minutes, the other on February 26–27. These photographs are in sharper focus in the blue region than the Johannesburg photographs, and are of assistance in confirming the existence of certain bright lines, suspected to be present on the Johannesburg photographs. The Bloemfontein spectra extend on the long wave-length side to about λ 5200 ; the Johannesburg spectra extend beyond *Hα*.

The spectrum is generally similar to the spectrum in 1933. The continuous spectrum is strong, with bright bands superposed. The strength of the continuous spectrum makes the detection of the weak bands difficult. The bands are broad, with ill-defined diffuse edges, and the wave-lengths, more particularly of the fainter bands, are necessarily somewhat uncertain.

The wave-lengths of the centres of the bands, as derived from the measurement of Johannesburg and Bloemfontein plates, are as follows :—

The Spectrum of Nova Pictoris, 1934

Observed λ	Tabular λ	Identification	Remarks
3759·5	3759·9	*O*III	Diffuse ; strong.
3841·3	3835·4	*Hη*	Very weak ; measure uncertain.
	40·2	Neb.	
3867·6	3868·9	*Ne*III	Weak.
3892·3	3889·1	*Hζ*	Stronger than preceding.
3970·3	3967·6	*Ne*III	Moderately strong.
	70·1	*Hε*	
4026·8	4025·6	*He*II	Very weak.
4071·3	4068·6	*S*II	Very weak ; measure uncertain.
4101·6	4101·7	*Hδ*	Strong.
4201·5	4199·9	*He*II	Weak.
4248·0	...	...	Suspected.
4291·2	...	...	Suspected.
4340·5	4340·5	*Hγ*	Strong.
4365·0	4363·2	*O*III	Very weak.

Observed λ	Tabular λ	Identification	Remarks
4542·4	4541·6	*He*II	Weak.
4584·4	...	...	Suspected.
4602·2	...	...	Weak and ill-defined.
4686·0	4685·8	*He*II	Very strong.
4726·9	4726	*Ne*IV	Weak.
4860·9	4861·3	*Hβ*	Strong.
4892·8	...	...	Moderately weak.
4942·0	...	...	Stronger than preceding.
4966·4	...	...	Weak.
4984·8	...	...	Broad blend, extending from 4975 to 5014. Structure and wave-lengths uncertain.
4992·4	...	...	
5007·0	5006·8	*O*III	
5156·3	...	...	Broad blend, 5148 to 5181. Structure and wave-lengths uncertain.
5168·8	...	...	
5173·3	?	? *F*II	
5276·0	?	? *F*II	Rather weak.
5309·7	...	...	Broad blend, 5303 to 5343. Wave-lengths of second and third lines uncertain.
5321·8	...	...	
5336·0	...	...	
5410·4	5411·6	*He*II	Weak.
5422·7	...	...	Overlaps preceding; wave-length uncertain.
5624·0	...	...	Doubtful; suspected.
5722·9	5725·1	*F*IV	Identification doubtful. Strong.
6087·6	...	...	Strong.
6563·0	6562·8	*Hα*	Strong.

The spectrum includes a number of broad blends, produced by the overlapping of the bands corresponding to neighbouring emissions differing in wave-length by only a few units. The limits of the bands have been given, together with probable wave-lengths of the component emissions, based upon measurement of the structure. The two edges of the strongest portion have been measured and the red or violet edge of the overlapping portions. The wave-lengths deduced from the measurement of an edge, assuming a band width, may be uncertain by as much as 3 A.

The following remarks refer to certain of the identifications in the above table :—

(1) The strong out-of-focus line at λ 3760 has been measured each year since 1926. It was remarked in the discussion of the 1933 spectrum that "Its identification with the *O*III line at λ 3759·9 appears probable, though no trace can be seen of the *O*III lines at λλ 3774·0 and 3791·3." * These lines, which are permitted lines, have relative intensities in the laboratory spectrum of 9, 6, 6 according to Fowler.† It has been a puzzle to me why the one line should be so strong in the nova spectrum, but no trace be found of the two lines of longer wave-length which are not much inferior in intensity in the laboratory spectrum. The explanation is now clear. Wright, photographing the ultra-violet spectra of a number of planetary nebulæ with the aluminised mirror of the Crossley reflector, found certain

* *M.N.*, 94, 37, 1933. † *Proc. R.S.*, **117**, 325, 1928.

permitted lines of *O*III to be present, but many other lines, including lines which are of greater intensity in the laboratory spectrum, to be absent.* He noted that the lines in the nebular spectrum are all members of multiplets that result from electron falls from the $3d\,^3P_2$ level, or from levels to which electrons readily pass from there. The explanation of the presence of these lines and of the absence of other lines of the *O*III spectrum has been given by Bowen † ; he attributes it to the near coincidence of the

$$(2p)^2\,^3P_2 - 2p3d\,^3P_2$$

transition of *O*III, falling at 303·799 ± ·010 A. with the resonance line of *He*II at 303·780 A. Thus a quantum of the *He*II line at 303·780 A., present in a nebula, can disappear by excitation of an *O*III atom to the $3d\,^3P_2$ state ; in falling from this state, the permitted lines found in the nebular spectra are emitted. Reverting to Nova Pictoris, the classification of the three *O*III lines referred to above is as follows :—

3759·9	$3s\,^3P_2 - 3p\,^3D_3$
3774·0	$3s\,^3P_1 - 3p\,^3D_1$
3791·3	$3s\,^3P_2 - 3p\,^3D_2$

These lines start from levels to which an electron can fall from the $^3P_2$ level. The figures given by Russell for multiple intensities in a triplet system ‡ show at once that the intensity of the λ 3759·9 emission, originating in a fall from the $3d\,^3P_2$ level, is much higher than that of λ 3774·0, which in turn is much higher than that of λ 3791·3. The relative intensities are such that the non-appearance in the nova spectrum of the latter two lines is satisfactorily accounted for. In further justification of Bowen's explanation of the appearance of certain of the permitted lines in the *O*III spectrum, it may be remarked that the λ 3759 line was first detected in the spectrum of Nova Pictoris on 1926 March 20. The next preceding competent plate was obtained on 1926 February 10. The λ 4686 *He*II line had not appeared in the spectrum on the latter date, whereas on 1926 March 20 it was very strong. The next spectrogram of the nova was obtained on 1926 March 28, when λ 4686 had weakened very considerably and λ 3759 was absent. This line was not observed again until 1926 September 7, when λ 4686 had also greatly increased in strength again. On 1926 September 17 λ 3759 was present and λ 4686 was strong, but by October 4 λ 4686 had diminished considerably in intensity and λ 3759 was again not detected.§ In subsequent years λ 4686 has remained a prominent line in the spectrum, and the λ 3759 line has always been present. The intimate relationship between *He*II and the permitted *O*III lines, pointed out by Bowen, is thus exactly confirmed in Nova Pictoris.

(2) The *He*II lines at λλ 4025·6, 4199·9, 4541·6 and 5411·6 have all been detected in the 1934 spectrum. During recent years these lines have not

* *Lick Obs. Bull.*, No. 459, 1934 ; *Pub. A.S.P.*, **46**, 142, 1934.
† *Pub. A.S.P.*, **46**, 146, 1934.
‡ *Proc. Nat. Acad. Sci.*, **11**, 324, 1925.
§ *Cape Annals*, **10**, pt. 9, 1931 (*vide* Table XLIV, p. 134).

been detected, though in 1928 they were all easily detected. In view of the increase in intensity of the continuous spectrum it is difficult to make a definite statement about absolute intensities. Allowing for the fact that the 1934 Johannesburg spectrum is stronger than those obtained in recent years, I am of the opinion that there has been a moderate increase in intensity of these lines. The *He*II 4686 line continues to be the strongest line in the spectrum.

(3) The lines at λλ 3868·9, 3967·6 have been attributed by Boyce, Menzel and Payne to forbidden lines of *Ne*III.* These lines first appeared in the spectrum about 9 months after the outburst, and the λλ 4959, 5007 lines of *O*III appeared at about the same time. They were strong in 1926 to 1928, but have since weakened and have not always been detected in later spectra, owing to the spectra not being sufficiently dense. Though weak, they are undoubtedly present in the 1934 spectrum. The weak line at λ 4726 has been attributed by Boyce, Menzel and Payne to *Ne*IV.* It was first detected in the nova spectrum on 1926 March 20, somewhat later than the *Ne*III lines. But as it was overshadowed by the *He*I emission at λ 4713·1 and the forbidden *Fe*II emission at λ 4728·1, it may have appeared earlier and escaped detection. The attribution of this line to *Ne*IV has been criticised by Swings and Edlén on the ground that the line should have a double structure.† The line is very weak, with ill-defined edges, but a double structure cannot be detected. The *Ne*V lines at λλ 3346, 3426, which are strong in the spectra of certain planetary nebulæ, are beyond the limits of the spectra.

(4) The very weak line, measured at λ 4071, may be the same as that which was present in the spectrum in 1926–28 at λ 4068, but which has escaped detection in recent years. It is present also in the spectrum of η Carinæ, and has been attributed by Boyce, Menzel and Payne to a forbidden line of *S*II. There is a weaker forbidden line of *S*II at λ 4076, which would be too weak for detection in the nova spectrum. The difference between the measured wave-length of the λ 4068 line and the true value may well be due to the uncertainty in the measurement of a very weak broad line and not to blending with the λ 4076 line.

(5) A weak radiation, which is apparently due to the forbidden *O*III λ 4363 transition, has persisted in the spectrum, though the nebular *O*III lines at λλ 4959, 5007 remained undetected in 1931–32–33. I have felt doubtful whether, if the typical N_1, N_2 lines were really absent from the spectrum, the attribution of the line at or near λ 4363 to *O*III could be regarded as correct. As, however, the definition of the Johannesburg spectrograms around λ 5000 is not very good and there is considerable blending of bands in that region, I have not felt absolutely convinced of the complete absence of the N_1, N_2 lines. The stronger spectrum available this year seems to indicate that λ 5007 is still present : in a broad band, extending from λ 4975 to λ 5014, the densest portion extending from about λ 4986 to λ 4998 corresponds to the line given as λ 4992·4. Weaker bands overlap this band both to violet and to red ; the wave-length of the centre

* *Proc. Nat. Acad. Sci.*, **19**, 581, 1933. † *Comptes Rendus*, **198**, 1748, 1934.

of the band to the red, inferred from the position of its red edge, is λ 5007, agreeing with the wave-length of the N_1 line. A weak band was also measured at λ 4966·4 ; in the 1928 spectrum a band was measured on the Johannesburg plates at λ 4963 and on the Cape plates at λ 4969, and interpreted as a blend between N_2 and a line of longer wave-length. A line at this wave-length has been measured in subsequent years. It appears probable, therefore, that the *O*III forbidden lines at λλ 4959, 5007 are still present in the spectrum, though weak, and that the statement of their disappearance in 1931 * was not justifiable.

(6) The strong line at λ 5723, which has been a prominent feature of the spectrum for some years, was identified by Boyce, Menzel and Payne † as due to a forbidden *F*III line, for which they computed a wave-length of 5725·1. This identification is criticised by Swings and Edlén,‡ who state that the assigned transition $^2D^0 - {}^2P^0$ is composed of two lines at λλ 5733·3, 5721·2 (± 1 A.), whose theoretical intensities according to Cardan are in the ratio 5 to 3·3. This appears to disprove the identification with the *F*III line, for the band at λ 5723 is not noticeably broader than those at 6088 and *Hα* ; moreover, the centre of the composite band would be at λ 5727, and so great a discordance between the measured and true wave-lengths is not possible for a band as strong as the λ 5723 band. If this identification is abandoned, the identification of the lines at λλ 5173, 5276 as due to *F*II, admittedly a very tentative identification, must also be abandoned. It may be remarked that Boyce, Menzel and Payne § state that the line at λ 5723 was present in the spectrum of Nova Aquilæ 1918, giving a reference to a paper by Paddock.‖ As this statement is repeated in the "Council Note on Variable Stars, 1933," ¶ it is necessary to point out that it is incorrect. In Paddock's paper a reproduction of the spectrum of Nova Aquilæ shows the strong band, typical of novæ at a certain stage, at λ 5753, and to the short wave-length side of it another band, incorrectly marked 4675 A. Boyce, Menzel and Payne have interpreted this as the λ 5723 line, but a reference to Paddock's measures (p. 248) shows that the correct wave-length is λ 5675, and that the λ 5723 band, if it had been present, would have overlapped the λ 5755 band. Neither of the strong bands at λ 5723 and λ 6088 have been found in the spectrum of any previous nova.

The relative intensities of the bright bands do not seem to have changed since the previous year. The *He*II λ 4686 band is still the strongest ; *Hα* is the next strongest with λ 6088 nearly as strong ; λ 5723 is a little weaker than λ 6088.

The stronger spectra available this year have made the measurements of band-widths possible. In general, the two edges of a band have been measured, the wave-lengths given in the above table referring to the mean of the two edges. For some of the weaker bands the settings were made on the estimated centres of the bands. The measures of band-widths are

* *Cape Annals*, **10**, pt. 9, p. 145, 1931.
† *Proc. Nat. Acad. Sci.*, **19**, 581, 1933.
‡ *Comptes Rendus*, **198**, 1842, 1934.
§ *Loc. cit.*, p. 586.
‖ *Pub. A.S.P.*, **30**, 244, 1918.
¶ *M.N.*, **94**, 351, 1934.

necessarily somewhat uncertain, the edges being very ill-defined. Expressed in terms of angstrom units they show an approximate proportionality with the wave-length. A proportional relationship was assumed and the constant of proportionality was derived from all the measures. The results obtained were :—

From Johannesburg plates : $10^4\Delta\lambda = 28{\cdot}7\ \lambda$
,, Bloemfontein ,, : $10^4\Delta\lambda = 31{\cdot}7\ \lambda$

where $\Delta\lambda$ denotes the width of the band whose centre is at wave-length λ.

The agreement is as good as would be expected, particularly as a slight trailing along the direction of dispersion would increase the measured breadths. Giving double weight to the Johannesburg plates, which have a wider range in wave-length and a larger number of bands for measurement, the final result is

$$10^4\Delta\lambda = 29{\cdot}7\ \lambda.$$

If the centres of the bands are regarded as undisplaced, this relationship corresponds to velocities of approach and recession for the violet and red edges respectively of 445 km./sec.

After the initial complex changes had passed and the spectrum had settled down, towards the end of 1925, to a simple bright band spectrum, the corresponding velocity, determined from the large scale Cape slit spectrograms, was 408 km./sec. The Johannesburg slitless spectrograms in 1928–29 gave velocities for the band edges of 435 km./sec. The later spectra, with their less-well-defined edges, longer exposures and the possibility of guiding error would be expected to give larger values. The velocity of 445 km./sec. derived above does not differ sufficiently from the velocity measured in 1925–26 to indicate any real change in velocity. The conclusion is that the band-widths in the spectrum in 1934, when expressed in terms of Doppler velocities, are the same as they were in 1925. Interpreted in terms of the expanding shell theory, the bright bands in the spectrum of Nova Pictoris in 1934, nearly 9 years after the outburst, are due to light from the nova which is absorbed and re-emitted from a gaseous shell, expanding at the same rate as it was observed to be expanding shortly after the outburst. The continuity in the spectral changes suggest that the bands have been produced throughout by the same shell which has been in continuous expansion.

It is generally accepted that the spectrum of an ex-nova gradually merges into that of a Wolf-Rayet star. The process of transition has never yet been observed. Beals * has interpreted the broad bands in the spectra of the Wolf-Rayet stars as due to the continuous emission of matter from the star. If a Wolf-Rayet star is an ex-nova, there would seem to be no reason why this velocity of ejection should bear any relationship to the velocity with which shells of gas were thrown off when the star was in a much-expanded state. Data as to whether the breadths of bands in the later stages of ex-novæ, when the spectra have been described as of the Wolf-

* *Pub. D.A.O.*, 6, No. 9, 1934 (*vide* Section II, p. 111).

Rayet type, bear any relationship to the breadths shortly after the outburst appear to be lacking.

The present spectrum of Nova Pictoris has certain general similarities to the spectra of Wolf-Rayet stars, in that it consists of broad bright bands superposed on a strong continuous spectrum; the band-widths are proportional to the wave-lengths, and the *He*II λ 4686 emission is the strongest in the spectrum. But, in so far as the composition of the bright emissions are concerned, the spectrum is unlike that of any Wolf-Rayet star, and is more comparable with the spectra of certain planetary nebulæ, such as N.G.C. 7027. The spectrum is still that of the expanding nebulous shell, which has apparently not yet dissipated sufficiently for the spectrum of the star itself to be observed. The slow decline in the brightness of Nova Pictoris makes it possible to hope that this important transition stage will be observed.

1934 *August* 26.

THE CONSTITUTIONS OF THE INNER PLANETS.

Harold Jeffreys, M.A., D.Sc., F.R.S.

Russell, Dugan and Stewart give the following values for the diameters (in km.) and densities (water = 1) of the inner planets and the Moon:—

	Moon	Mercury	Mars	Venus	Earth
Diameter . . .	3476	5000	6770	12400	12742
Density . . .	3·33	3·8	3·96	4·86	5·52

The order of increasing diameter is also that of increasing density. I do not know whether any explanation of this relation has been offered. It might be thought that the extra density of the larger bodies was due to compression, but this has been investigated by L. H. Adams and E. D. Williamson and found to be inadequate in the case of the Earth.* It therefore represents a difference of composition. The geophysical evidence indicates that the Earth consists of a silicate shell about 2900 km. deep, resting on a core of liquid heavy metals, probably chiefly iron. The density of the shell, if the pressure was removed, is inferred on several grounds to be about 3·3; the chief constituent is probably olivine $(Mg, Fe)_2SiO_4$. The density is nearly that of the Moon, for which the effect of compression must be small, so that the Moon is probably destitute of a core. By interpolation we can infer that the variation of density among the other bodies is mainly a matter of the size of the metallic core with respect to the whole size. Our present knowledge of the elastic properties of the Earth would make it possible to determine the sizes of the cores in Mercury, Venus and Mars fairly accurately from the mean densities; one useful astronomical result would be a new determination of the ellipticity of Mars.

* *J. Wash. Acad. Sci.*, **13**, 413–428, 1923.

The purpose of this note is to call attention to the cosmogonical problem arising from the variation of composition. Jeans and I have several times pointed out the difficulty of slow condensation of bodies of the dimensions of the planets from a gaseous state, since at a high distension gravity would be unable to prevent diffusion into space, especially if condensation was slow. The low densities of the great planets have been attributed to their greater ability to retain gases and water vapour in their early state. Now the collision theory and the tidal theory both require that the ribbon or filament that gave rise to the planets broke up as fast as it emerged from the Sun, and the formation of separate planets in their primitive state was a matter of hours at most. In these conditions it is hard to see how any separation of constituents could occur except by loss of gases from the outside ; the terrestrial planets, therefore, having lost their gases, should have the same constitution as regards the materials of high boiling-point as the Sun. The catastrophic theories seem therefore to leave no room for the actual differences of composition between them. It is easy to understand how they can have lost hydrogen and other materials of low boiling-point, but it is very difficult to see how the Moon, Mercury and Mars can have lost iron in excess of silicates.

On the face of it, the differences of composition suggest that the materials had time to separate after they left the Sun; in other words, that the terrestrial planets originally formed only one or two bodies, and that the iron had time to settle to the centre before they acquired their present individuality. But this seems to be inconsistent with the argument for a catastrophic origin of the planets, and raises afresh the problem of how such a body could be broken up ; neither rotation, direct solar tidal action nor resonance seems adequate.

St. John's College, Cambridge :
1934 *August.*

THE ZODIACAL BAND.

Rev. R. B. Bousfield, M.A.

(Communicated by Prof. F. J. M. Stratton)

1. *Introductory.*—Since 1931 January the Zodiacal Band has been kept under regular observation, when conditions have been favourable. Some 500 morning and evening appearances of the zodiacal light have been charted and a special study has been made of the Zodiacal Band, as distinct from the evening and morning cones. The observations have been made from the roof of my house at Stanthorpe, Queensland, at a height of 3000 feet above sea-level. The co-ordinates of the observing station are 28° 40′ S. and 151° 55′·5 E. The zodiacal light work was undertaken under the direction of the Director of the Zodiacal Light Section of the British Astronomical Association and consisted at first of rough visual estimates

of the Zodiacal Cones, their boundaries and their brightness. Later more exact photometric methods were adopted. This paper contains an account of the more interesting phenomena observed in the course of the work.

2. *Instruments.*—For charting the Zodiacal Cones the following device was used : A rectangular frame, capable of being turned to any angle, was mounted on a pillar on top of the roof. Parallel to one side of the rectangle a bar was mounted fixed in the plane of the frame and sighting wires were mounted in a plane at right angles to the rectangle and through this fixed bar. By using ecliptic stars down to the fifth or sixth magnitude I was able to set the rectangle so that the fixed bar was parallel to the ecliptic near the apex of the Zodiacal Cone ; with the aid of the sighting wire I also fixed a point relative to the frame, from which to make my observations. The positions of the edges of the cone and also of an outer shell, if observed, relative to the ecliptic were fixed by setting some steel rods, movable in slots in the plane of the rectangular framework, stars falling on or near any of the rods being marked by gummed paper on the rods after adjustment. After completion of the adjustment a true horizon line was given by a spirit-level and the whole framework was taken inside the observatory ; the observations were then reduced to scale and plotted on a prepared stellar map in a chart book kept for the purpose. So far as possible one diagram was secured on one evening and one early morning in each month, giving a sequence of the changes observed.

In my photometric work I made use at first of an uncalibrated lumeter made by myself on the lines laid down by Messrs. Dow and McKinney in 1912, but in 1932 the generosity of the late Mr. Gavin Burns put into my hands the original holophane lumeter, which he had adapted for work on the luminosity of the night sky. In 1932 November I took this photometer to Professor Parnell and Professor Luscombe at Brisbane University. They very kindly supplied standardised, tested bulbs and calibrated the instrument to give the illumination in terms of foot-candles. The instrument is a visual photometer, depending on the equalisation of the standardised light (falling on an opal glass screen after passing through a calibrated blue filter) with the external light seen through an aperture in the illuminated screen. The bulb was calibrated at a fixed current of 275 milliamperes and the current controlled by a rheostat was tested between each observation to avoid creep. The distance of the bulb from the screen could be varied : it was also possible to control the size of the aperture in the opal glass diffusing screen, through which the light passed to the final illuminated screen. The instrument was calibrated for varying positions of the lamp and for varying apertures, and Professor Parnell estimated the errors of observation at about 5 per cent. The eyepiece was set diagonally to the box and was furnished with an eye-lens. In the line of sight at a fixed distance outside the aperture in the illuminated screen an out-of-focus lens was placed. In my experience the use of the two lenses had very little effect on the observed values of the illumination. To balance a fairly bright light, such as the clouds in Sagittarius and Scutum proved easy. The fainter the light, however, the harder it proved to get the exact point of

balance between the screen and the skylight. The ability of the eye to distinguish differences between excessively dim lights is limited. For such

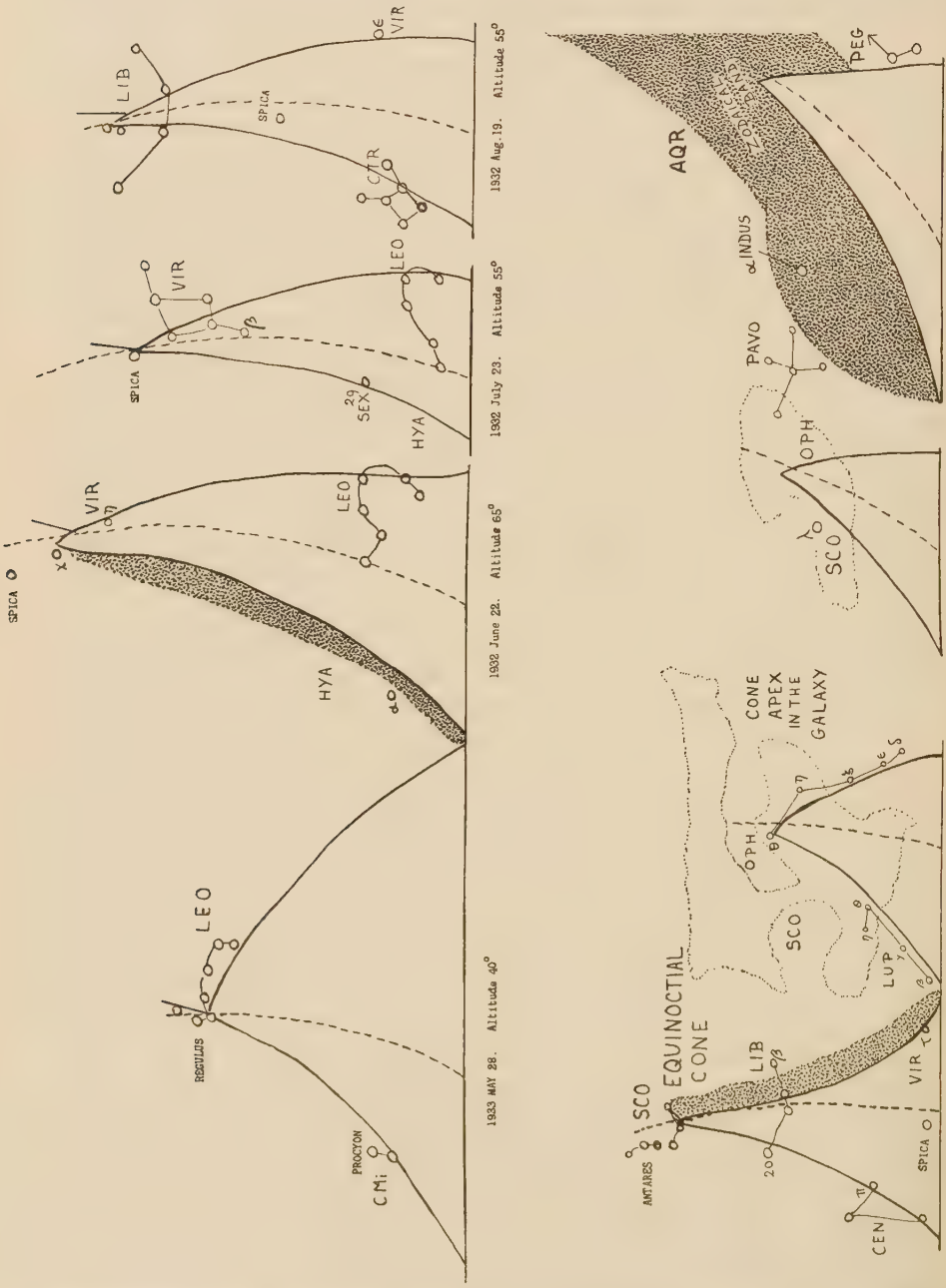


FIG. 1.—*Zodiacal cones. Seasonal phases of the evening apparitions.*

observations it is desirable to replace the eye by a photo-electric cell, and it is hoped to do so at some later date.

3. *Zodiacal Cones.*—The first point that strikes an observer working regularly from one station is the orderly succession of phases of the cones,

repeated year after year. Save for vagaries of atmospheric conditions the behaviour of the cones is very fairly predictable. The accompanying

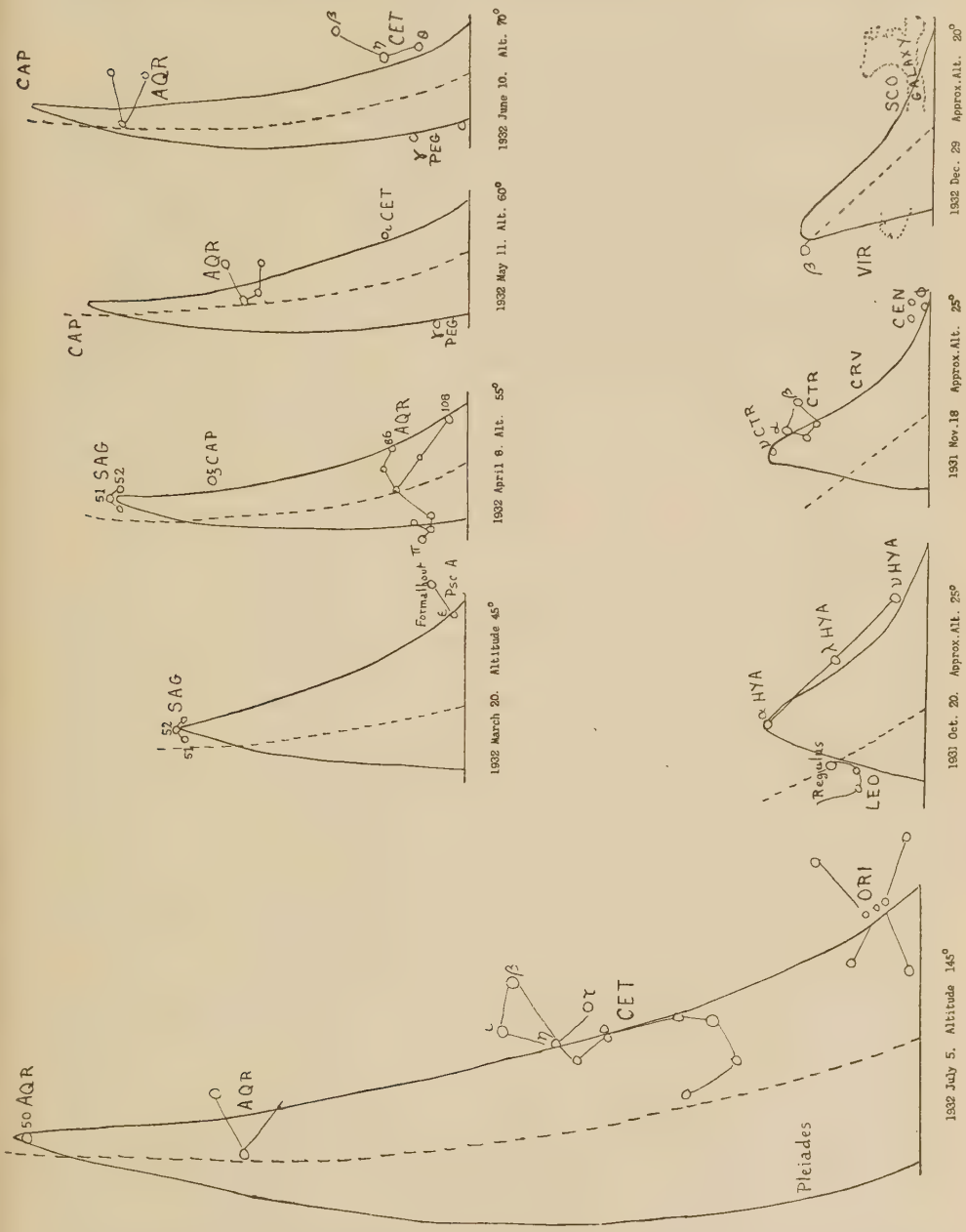


FIG. 2.—*Zodiacal cones. Seasonal phases of the morning apparitions.*

drawings show the shapes of the evening and morning cones and the altitudes to which they have been followed in the different months of the year. From January to March when the ecliptic is low in the evening the cone loses its form extending far to the south on one side ; it varies in appearance

from a vast semicircular fan to a ribbon-like form mounting from the south with a vague apex near the ecliptic and a sharp drop in intensity at the northern edge. From March to May the slope becomes more defined and the rounded apex more settled. At the same time, from the March equinox onwards, the morning cone changes very rapidly in form. The great width of base and the atmospheric diffusion cease ; the outer shell of haze vanishes and the base rapidly narrows ; a long finger of light shoots almost vertically upwards. The vertex of the cone reaches to 50, 51, 52 Sagittarii when the presence of the Milky Way interferes with the delineation of the cone. On one occasion, between 4.0 and 5.0 (local mean time) * on 1932 July 5, I was able to observe an Eastern Zodiacal Cone extending well beyond the zenith to the star 50 Aquarius.

But I must return to an observation at 5.0, 1931 July 15, when for the first time I understood the meaning of a western glow which I had seen at a number of morning observations and which had puzzled me. When I opened the roof, which was covered with ice, the temperature being 7° below freezing-point, I saw in a dark scintillating sky that Kipling's lines "East is East and West is West, and never the twain shall meet" had been magnificently falsified. In the East and West alike there were two truncated cones, which resembled flying buttresses for a vaster arch, flung almost overhead and between 32° and 34° in width. The eastern buttress was the brighter ; it faded to what appeared to be between a quarter and an eighth of its brilliancy at the zenith, but two-thirds of the way to the western horizon the light strengthened again the western buttress for its lowest 25° being about half as bright as the eastern one. Beyond the well-defined boundaries of white light there could be seen an outer shell of a few degrees north and south of a coppery hue. It was my privilege to witness the Australian Total Solar Eclipse of 1922. But the vision that presented itself that early morning has left as abiding and transcendent an impression as the darkness and the Solar Corona in 1922. Its superb grandeur was beyond any adequate expression by tongue or pen.

Leaving to a later section the discussion of the Zodiacal Arch or Band I pass to a few other morning observations on the eastern and western cones. The following extracts are from the observation book :—

1932 Sep. 15, 3.0.—Western Cone well formed with a clear apex at about ϕ Aqr. The base towards Corona A. on the South and Delphinium on the North—now both below line of vision. Luminosity less than at midwinter.

Eastern Cone—shapeless and submerged in the Galaxy. The Zodiacal Band Arch—visible but hazy and dim ; but outlines visible as before.

Sep. 19.—*No Eastern Cone* except a dim haze on the horizon after waiting till the Galaxy was some 20° above the horizon. No zodiacal band, the latter having grown continually fainter with the approach of spring.

But a well-formed and very distinct pyramidal Western cone with a fine apex and slender width sloping along the ecliptic till shortly before dawn.

* The time used in this paper is Standard Eastern Australian time—10 hours E. of Greenwich.

Sep. 22, 4.0.—Conditions unchanged.

Sep. 24.—Cloudless sky. Very faint traces of Eastern Cone.

West Cone—now dim, but running through Psc as before in a thin luminous finger-cone to an apex at about the colure.

At this point the Moon interrupted further work in the mornings. The next observation is on October 13 at 3.45. *The East Cone had returned, but the West Cone was now very faint.* But the East Cone had shifted its apex to what must be regarded as the extreme southerly edge of the Zodiacal Band itself.

There seems no doubt from subsequent observations in 1932 and 1933 about this swing southwards of the apex in October and November and its return to normal just after the summer solstice. It has nothing to do with the true axis of the Zodiacal Band, but is presumably to be explained in terms of the varying seasonal position of the ecliptic at different seasons in the early morning hours. I have, it should be added, failed to detect similar swings of the apex in the evening cone in the West.

Another curious phenomenon that I have witnessed frequently in mid-winter lies in the orderly alteration of relative intensities of the eastern and western cones. This was noted especially in 1931 July, when I made the following entry in my observation book :—

"A curious feature observed repeatedly. The Western horizon seems to begin to rebrighten between 2.0 and 3.0 a.m. It reaches a high intensity about $3\frac{1}{2}$ hours before sunrise, being then bright while the East is still much less so. About two hours before sunrise the Eastern Cone begins to increase its intensity, while the West appears to go duller ; and the East now outmatches the West till dawn. The moment of dawn can be adjudged to within a minute or two. Its sudden effect is unvarying and resembles the sudden hop of light in a room when the power-house has been sending a diminished current or starts up the engine. The change of maximum from West to East occurs long before this 'hop,' and it has no connection with the terrestrial dawn. That the West does brighten first and the East overtake it is a reality, which measurements with the lumeter bear out as a fact. But why so, is to me a mystery."

Equally curious is the building of the arch in February. It is an exact reversal of the long autumn process that extends from East to West, but a process that is completed under the eyes in a few hours. The evening apparition tails ever farther and farther eastwards till the zenith is passed near midnight. Finally, between 2 a.m. and 2.30 a.m. the East leaps up to meet it and the great bridge is complete. Gradual change in the conditions of observation (*e.g.* slope of the ecliptic, night-sky illumination, atmospheric transparency) must contribute to this result, as observations taken throughout a night and morning at a fixed altitude show, steady changes which would suggest as natural the gradual shortening of the Western Cone as the evening progressed. Thus observations with the lumeter taken throughout the night and morning of 1934 April 17–18 gave the following figures for the hourly change :—

West Cone. 10° *above the Horizon*

April 17	Luminosity
19.00	·0035 foot-candles
20.00	·0020 ,,
21.00	... (In the Galaxy)
22.15	·0014 foot-candles
23.00	·0011 ,,
Midnight	·0009 ,,

East Cone. 5° *above the Horizon*

Midnight	·0009 foot-candles
1.00	·0009 ,,
2.00	·0009 ,,
3.00	·0019 ,,
4.00	·0031 ,,
4.45	·0049 ,,
4.50	Twilight commenced
6.11	Sunrise

On the night of the above observations there was no wind and not a cloud in the sky all night long. The night-sky luminosity in general was very low outside the zodiacal light.

4. *Zodiacal Band.*—My first observation in 1931 July of the full zodiacal arch is described above. Feeling that the arch near the meridian gave me the best opportunity of plotting the boundaries of the Zodiacal Band, clear of the most disturbing features, I rose early morning after morning to observe the Band, resting my eyes for twenty minutes in the dark before starting to observe. At first I used star charts illuminated by a dim light for plotting the boundary, later I used charts prepared beforehand on a transparent paper in a box with a glazed surface containing a minute oil-lamp ; I thus eliminated all glare effects. The charting was executed from star to star, using magnitudes down to the lowest recorded in Norton's atlases. Allowing for alternate fortnights between lunar periods I was able from July to September continually to advance the zenith area of chart work : every morning I charted a small area with extreme care, ultimately charting a large span of sky before the Band ceased to shine.

The arch reappeared in 1932 February, when daily charting was resumed. For the position plotted during these autumn months the faintness of the Band in comparison with July did not admit of such certainty to northwards as might be desired. The southern boundary may, however, be accepted as fairly accurate. It may be noted that the shift of the eastern apex noted in October was to a point coincident with the southern boundary of the Band with great exactitude, though this southern boundary was only plotted later. I have supplied a map on which all the stars concerned have been entered, together with the Galaxy, the equator and ecliptic and the Zodiacal Band as charted. The boundaries are also given in Appendix II. No attempt has been made to enter the area between α Hya and the Galaxy, because the broadening of the base was too extensive and would have involved guess-work, while the limited period and hours did not permit this

area to be examined upon the zenith. It probably runs close to 25 Mon. An examination of the chart will show that at opposite points near the solstitial colures there is a narrowing of the Band on the north side of the ecliptic. It seemed incredible that the Band did not extend farther north

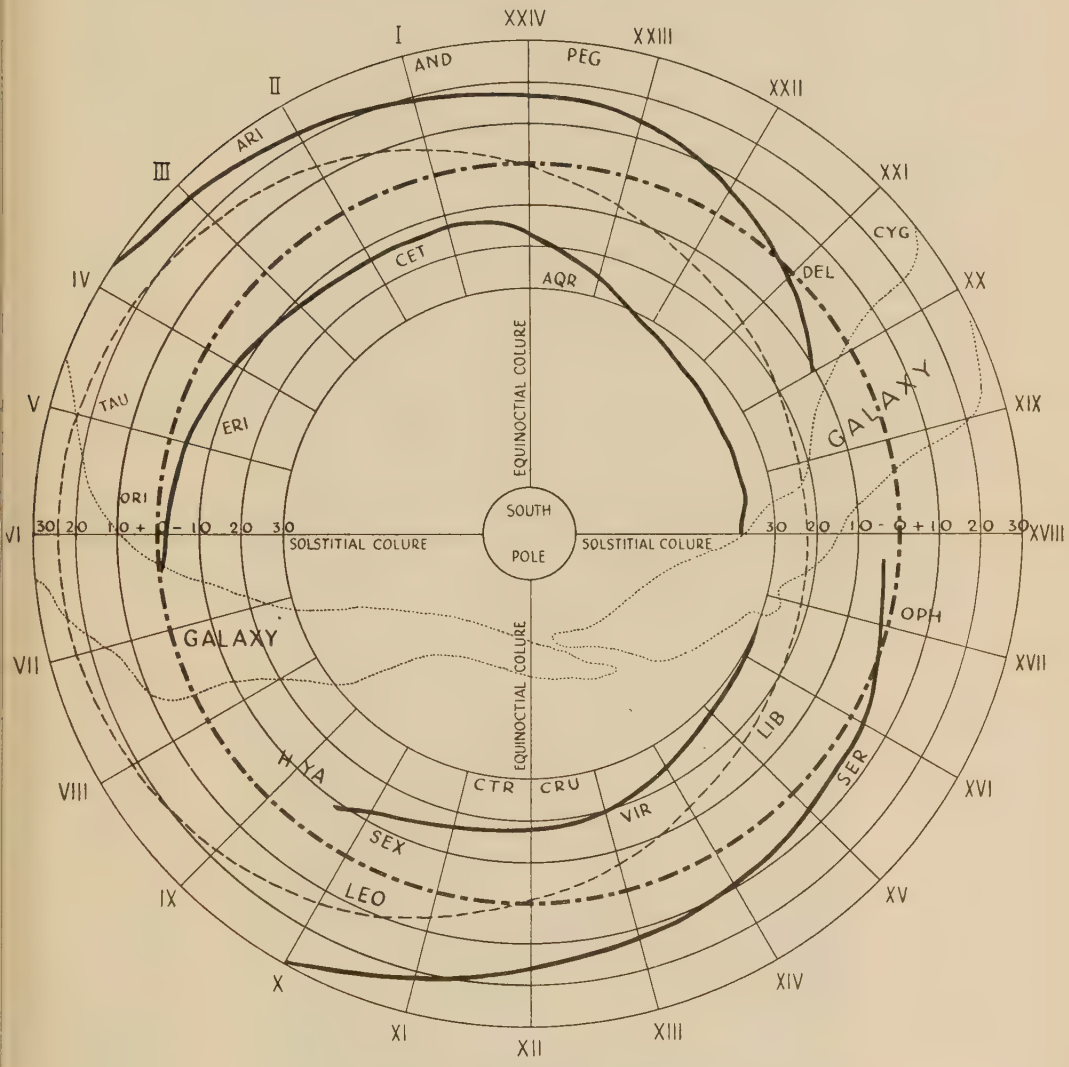


FIG. 3.—*Zodiacal Band Chart* 1931, 1932, 1933.
——— *Boundary of Zodiacal Band.*
– – – – *Ecliptic.*

than β Arietis, and yet it seemed impossible to trace it beyond that point. This star is the most northerly point at which the Band is seen against the sky from this southern latitude ; though it is far above the horizon it represents presumably the limit at which atmospheric absorption cuts out the faint light of the Zodiacal Band. Comparison with observations made in the northern hemisphere at this part of the Band seems to be called for, and

it may throw light on the physical meaning of the differences found between the results of observers in the northern and southern hemispheres.

Another point where comparison of northern and southern observations may come in usefully as throwing light on the nature and origin of the illumination of the Zodiacal Band is in a study of the relative sharpness and brightness of the northern and southern edges. My observations show that when the ecliptic slopes northwards the south edge is brightest and the Band tends to shade off gradually with a poorly defined edge on the north side. When the ecliptic is nearly overhead the edges are of nearly equal brightness—occasionally the northern edge being seen as the brighter—but the northern edge is now the sharper in definition.

Accompanying this paper is a photograph (Plate 6) from a water-colour painted by Mr. Jarvis of Stanthorpe, who acted as official artist of the 1922 Total Eclipse Expedition organised for the B.A.A. by Mr. Gale. The stellar background was prepared by myself for the northern sky as seen from Southern Queensland at about 4.0 on a February morning. The sketch truthfully displays the Zodiacal Band along the limits seen at Stanthorpe. The eastern end is brightest; there is a falling off of brightness at the top of the cone and at the western end there is a rise in light value; a secondary maximum occurs which reaches right to the horizon.

The following photometric observations give a fair estimate of the luminosity ratio of the bases of the two cones to the arch. As a slight check on the effect of altitude on the absorbing power of the atmosphere supplementary observations are added on Nubecula Major at different altitudes :—

Date	Time	Altitude		Foot-candles
1933				
July 22	4.0–5.0	East Cone at	10 degrees	·0053
		To East of Zenith of Arch	80 ,,	·0029
		Zenith of Arch	90 ,,	·0026
		West of Arch at	10 ,,	·0047
		Night-sky luminosity at darkest point of sky between Canopus and Lepus		·0016
		Nubecula Major at	10 ,,	·0035
		Nubecula Major at	35 ,,	·0041
July 31	4.0–4.30	East at	10 ,,	·0053
		Zenith of Arch	90 ,,	·0019
		West at	10 ,,	·0034
		Night-sky luminosity at darkest point, between Canopus and Lepus		·0015
Aug. 1	5.0	East at	10 ,,	·0047
		Zenith at	90 ,,	·0024
		West at	10 ,,	·0031
		Night-sky luminosity at darkest point, between Canopus and Lepus		

R. B. Bousfield, *The Zodiacal Band.*

Date 1933	Time	Altitude		Foot-candles
Aug. 3	5.0	East at	10 degrees	·0047
		Zenith at	90 ,,	·0015
		West Base at	10 ,,	·0028
		Night-sky luminosity	...	·0012
Aug. 24	3.30	East Cone submerged in Galaxy	...	...
(West Base fading)		Zenith of Arch	...	·0022
		West Base at	10 degrees	·0028
		Retested Nubecula Major at	10 ,,	·0031
		Nubecula Major at	40 ,,	·0043
Aug. 28	...	Western light had fallen off to such a degree that it was equal only to the Band at Zenith. Observation taken at very early hour to escape the Galaxy		
(Very early. East dull.)	2.30–3.0	East Base at	10 degrees	·002
		Zenith and West both	...	·001

5. *The Gegenschein.*—I rarely see the Gegenschein, perhaps on account of the extreme brilliancy of the Band. But I charted it one evening when the Band was invisible in 1931 October, from eye observations, giving limits closely corresponding to those found at Yerkes. The brightest patch was close to the anti-sun at R.A. $12^h\ 56^m$, and $\delta + 6°$, but the surrounding weaker patch was eccentric, being elongated in the direction of decreasing right ascension or towards the meridian. This may have been due to atmospheric reasons or to the variation of absorption with altitude. The difficulty of allowing properly for these disturbing factors leaves open the question whether the brightening of the Western Cone in the early morning referred to above may have been due to the presence in it of the maximum of illumination which has been so often recorded in the Gegenschein. I have not as yet succeeded in securing photometric observations of the Gegenschein.

6. *Lunar Zodiacal Light.*—In a monumental volume published by the Naval Department in Washington * the Rev. George Jones discusses a number of observations that he has made suggesting illumination of zodiacal light matter by the Moon. I give in Appendix I extracts from my observation books on observations of the Western Cone in the early morning. They do not bear out, by special connection with lunar phases, the idea that the anomalies described above are to be explained in terms of a lunar contribution to the zodiacal light. For while the period of the New Moon frequently displays a dull cone and the period of the Full Moon frequently shows a bright light, no definite rule establishes itself. In particular, one observation on 1934 March 16, at 3.30, one night after New Moon, when a Western Cone was clearly visible with well-defined boundaries rising to

* *United States Japan Expedition*, vol. iii, "Observations on the Zodiacal Light from 1853 April 2 to 1855 April 22," by the Rev. George Jones, A.M. (Washington, 1856). I possess an annotated copy presented by the author to Sir William Herschel.

an apex at η Virginis at an altitude of 45°, shows clearly that the Moon is not a necessary factor in rendering the Western Cone visible in the morning. Other observations made on the Eastern Cone in the evenings proved equally inconclusive.

The question of lunar zodiacal light is tied up with the position relative to the Earth of the matter forming the Zodiacal Band. If the lunar zodiacal

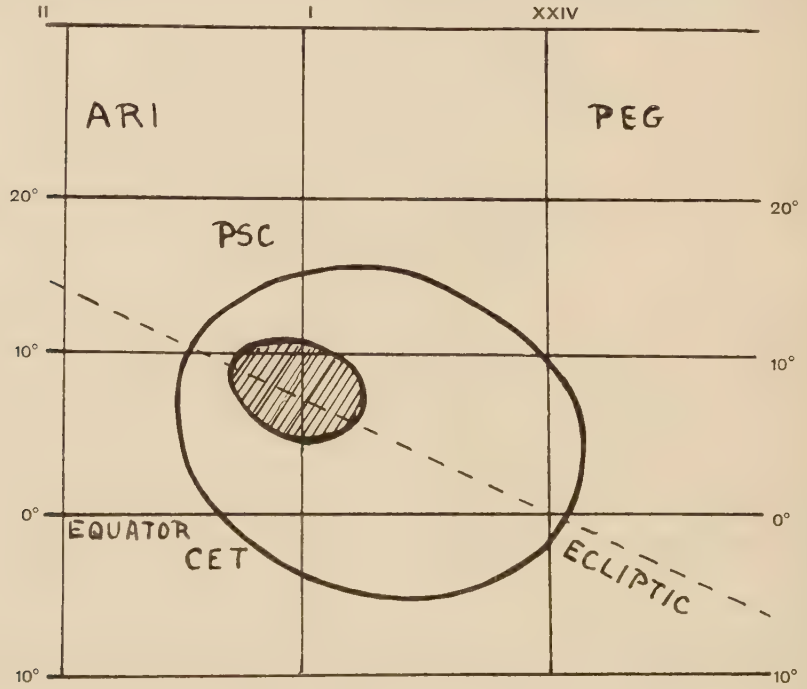


FIG. 4.—*Gegenschein*, 1931 *October* 9^{d} 21^{h}.

light is finally confirmed, it means that part at least of the matter is near the Earth, presumably inside the lunar orbit. It occurred to me that such a distribution of the matter might be tested by the lifting of a shadow or the darkening of the Band after a solar eclipse. For the annular eclipse of 1933 August 23, which ended close to sunset in Queensland, I endeavoured to organize a chain of observers from Northern Queensland down to Broken Hill in the south, arranging for charted observations on the night preceding the eclipse and on the eclipse night. Unfortunately owing to cloudy conditions over the whole of the Eastern Continent, with rain and thunderstorms, only two observations could be made. Mr. W. F. Gale observed shortly after dusk in Sydney across the harbour. He is a very experienced zodiacal light observer, but on the night of the eclipse he could see no sign whatever of the Western Cone. His observation might have been affected, as he notes, by the harbour lights and by a slight haze to westward.

I happened to be the other fortunate observer. At 8.40 p.m., presumably about 90 minutes after Mr. Gale's observation, the sky cleared completely for ten minutes, giving a very clear atmosphere ; after that interval

it clouded again and rained. But I had been waiting ready all evening and was able to take a double observation. I found that up to about 30° the base of the Western Cone was bright, at 0·0045 foot-candles, but at this altitude and beyond it up to the apex at 65° a sudden drop occurred to 0·0037 foot-candles; there was a clear line of demarcation which was noted each time the holophane lumeter swept across it. This was an observation which I have entirely failed to repeat on other evenings; on the following night, for instance, the light for the whole cone from close to its base up to its apex gave 0·0045 foot-candles. For some reason, not yet explained, on the night of the eclipse and on that night only this sharp line of varying brightness was found in the cone. A single observation of this kind cannot be regarded as conclusive, but it is at any rate sufficiently suggestive to call for more refined observations by astronomers suitably placed at some later eclipse.

7. *Undulations.*—My own conviction is that the light of the Zodiacal Band is not constant. I have no doubt that it was brighter in 1931 than in 1932 or 1933. The morning arch in 1931 July was extraordinarily brilliant, the 1932 February arch was extremely bright, the 1933 February arch was less bright, though clearly seen; the 1934 January arch was seen, but it disappeared entirely in February and was not seen in March. In addition to these changes, which in the absence of independent support by other observers may have to be explained by varying conditions of observation, I have in common with Jones and other observers noted undulations in the brightness. These I have noticed more pronounced in the morning in the east: the waves are long and wide apart, while at night to the west they present more of a ripple effect, are closer set and harder to define. It is not a common effect. When I first noticed these undulations I had no knowledge that others had observed the phenomenon, but I found later that Jones described pulsations with a period of a minute or two in 1854, ascribing it to something intrinsically connected with the light itself, external to the atmosphere. Denning * quotes a description of pulsations with a period of 30 seconds observed by Lowe in 1850, and attributes the effect to eye-strain. I have endeavoured to test this physiological explanation. After watching the undulations for some time without any attempt at strain, I turned to a portion of the Galaxy of large extent and similar luminosity. I gazed at it for a long time and even attempted to produce eye-strain and to tire the optic nerve. But the Galactic light remained absolutely steady under identical conditions of atmosphere and altitude. I could not perceive the faintest trace of undulation. Returning my gaze to the cone, it continued, majestically sweeping its widely spaced aerial rollers one after the other from base towards apex, one billow of light silently succeeding another.

The most striking observation that I have noted was on 1931 May 27, at 2.15. I quote from my notes:

"I was forcibly struck by undulations which stretched from north to south boundaries in the base and rolled up the narrowing shaft like ocean

* *Splendour of the Heavens*, p. 184.

rollers being pushed up an estuary from the open sea. As they progressed in horizontal crests they narrowed in width, vanishing at the apex, as a wave might vanish at the end of a funnel-shaped inlet. There appeared to be several wave-crests simultaneously visible."

From observations on subsequent nights the height of the cone (not recorded for May 27 at 2.15) may be taken as 70°, and my memory is that at least three crests could be seen at one time and that it took about $2\frac{1}{2}$ seconds for a crest to run from base to apex.

It may not be without significance that on the following morning, 1931 May 28, between 3.0 and 3.30 there was a very strong horizon glow, so brilliantly illuminating the whole east and south-east that it threw all the trees and distant hills into bold relief.

8. *Conclusion.*—I have attempted no theory to explain the phenomena described above. I have contented myself with recording observations as accurately as my instrumental means allowed, leaving to others the explanation, but hoping that the observations may contribute to the solving of outstanding problems.

Stanthorpe.

APPENDIX I

Variations in the Western Light before Dawn, with Lunar Phases in the Margin

Year 1931	Time		Lunar Phase
Apr. 22	4.30 a.m.	*Bright western patch* size of Pegasus Square.	4th day
,, 23	4.30 a.m.	*Very bright patch in West.* Estimated Sag. Cloud.	5th ,,
May 20	4.45 a.m.	"Western Light ascending to some height."	2nd ,,
July 15	5.0 a.m.	Full Arch appeared. *West Light between half and two-thirds Light of Eastern Cone.*	*New Moon*
,, 17	5.0 a.m.	*West Cone equalled one third East Cone Light.*	2nd day
,, 25	4.50 a.m.	West Light as far as Delph. to North. Arch.	10th ,,
,, 26	3.0–5.0 a.m.	*West Light somewhat dimmer.*	11th ,,
,, 27	2.0–3.30 a.m.	West exceeds East intensity till 2.30, after which East becomes the maximum.	12th ,,
Aug. 17	4.45 a.m.	East Cone equals Can. Min. area of Galaxy. West Cone equals Nubecula Mi (dim?).	3rd ,,
,, 18–23	4.0 a.m.	*West and East Light now notably dull.*	4th ,,
,, 25	4.15 a.m.	East Cone in the Galaxy, but *West Cone far outshone* the apparent combination, and had a base 60 degrees, North to South. But at 5 a.m. became duller and East outshone it.	12th ,,
Sept. 15	3.0 a.m.	*West Cone now duller* than midwinter.	3rd ,,
,, 19	4 a.m.	No East Cone, and *West between third and half Galaxy in Can. Min.*	7th ,,
,, 22	4.0 a.m.	Faint spot of light in East, but *West Cone bright as on 19th inst.*	10th ,,
,, 24	4.30 a.m.	*West Cone now dim.* Thin, luminous finger running through Pisc. to Equinoctial Colure.	12th ,,
Oct. 9	5.22 a.m.	*West Cone faintly seen.*	25th ,,
,, 13	3.0 a.m.	West Cone *very* faintly seen.	2nd ,,
,, 17	...	*West Cone invisible.*	6th ,,

Year 1931	Time		Lunar Phase
Nov. 18	3.0 a.m.	Indeterminate Western Light seen over ecliptic—now very slanted—near horizon.	8th day
Dec. 13	3.0 a.m.	*West Cone fairly bright.* Equalling Can. Min. in Galaxy.	11th ,,
1932			
Feb. 11	3.45 a.m.	Return of the Full Arch. *West Cone equalled Galaxy near Castor and Pollux.*	4th ,,
,, 13	2.30 a.m.	West Cone with no axis, but *intense line* horizontally equal East at that hour.	5th ,,
,, 14	3.0–4.0 a.m.	West Cone a little less in intensity than Canis Major area of Galaxy.	6th ,,
,, 16	3.30 a.m.	*West Cone and Arch so dim as to be negligible.*	8th ,,
,, 17	3.30 a.m.	Western Light now "low, flat and dim."	9th ,,
,, 18	3.30 a.m.	Truncated, dim but distinct.	10th ,,
,, 19	3.0 a.m.	East, Sag. Clouds. West, Can. Min.	11th ,,
Mar. 3	3.0 a.m.	Respective luminosities unchanged.	24th ,,
Apr. 9	2.0 a.m.	East Cone bright. No West Cone at all.	3rd ,,
July 29	5.0 a.m.	*Arch with well-formed Western Cone.*	25th ,,
,, 31	4.0 a.m.	Unchanged luminosity in the West.	27th ,,
Aug. 1 and 2	4 a.m. (dim)	West Cone only equal to Arch at Zenith. *New Moon.*	Aug. 1 = *New Moon*
,, 4	4.0 a.m. (dim)	West now ·002 foot-candles less than Zenith.	2nd day
,, 6	5.0 a.m. (dim)	Light ratio of West and Zenith unchanged.	4th ,,
,, 7, 12 and 13	4.50 a.m. (dim)	West Light and Band Light equal.	5th ,,
,, 14	5.0 a.m.	Slight rise. West ·002 foot-candles brighter than Arch. (July and August atmospheric conditions bad. Great night-sky luminosity of milky texture this year.)	12th ,,
Oct. 9	3.30 a.m.	In West, very faint band of Light above Aqr. In East, faint glow below Hya. But no Band.	9th ,,
,, 11	4.0 a.m.	*Very faint Western Glow.* No Eastern Light. No Band.	11th ,,
		[*Regrettable gap.*]	
1933			
Feb. 12	3.30 a.m.	Thin crescent of waning Moon in East obscuring East Cone. But *Clear Cone again in the West.*	16th ,,
,, 23	3.30 a.m.	East Cone. No Band. *Clear West Cone.*	27th ,,
,, 24	...	East Cone. Faint Arch and *Clear West Cone.*	28th ,,
Mar. 1	3.30 a.m.	East Cone. No Arch. But *West Cone very dim. . . .*	3rd ,,
,, 17	...	Slender autumnal Cone in the East. But a *clear localised semicircle of fairly bright light*, West . . . covering $\beta, \eta, \gamma, \delta$, Vir. If the Gegenschein, the South side of ecliptic hardly touched? But Gegenschein would be between γ and η Vir. Equal to light midway between Procyon and Syrius.	19 days
		[*Further regrettable gap.*]	
		Photometric Estimates	
July 22	4.5 a.m.	*Calibrated readings*—West equalled ·0047 foot-candles	27 days
,, 31	4.43 a.m.	West equalled ·0034 ,,	8 ,,

Year 1933	Time		Lunar Phase
Aug. 1	5.0 a.m.	West equalled ·0031 foot-candles	9 days
,, 3	5.0 a.m.	West equalled ·0028 ,,	11 ,,
,, 28	3.30 a.m.	West equalled ·0028 ,,	7th day
		Western Cone imperceptible against the sky.	
Sept. 15	3.0 a.m.	10 minutes before Moonrise in the East. East light purely atmospheric. A glow had mounted with an apex on Betelgeuse, right off the ecliptic. *In the West, a very dim and low light* on the ecliptic just visible again.	24th ,,
,, 20	4.0 a.m.	East Cone gave a bright glow near horizon in Cancer area. No Zodiacal Band visible. But an *extremely feeble glow on the Western horizon.*	*New Moon*

APPENDIX II

Zodiacal Band Limits charted from 1931 *to* 1933

Winter Zone

North Edge	*South Edge*
ζ Per.	ϵ Ori.
49 Ari.	δ Eri.
β Ari.	π—σ Cet (1931).
γ Peg.	θ—η Cet (normal width).
θ Peg.	(β Cet always beyond limit.)
β Aqr.	108, 101, 86 Aqr (1931).
ϵ Aqr.	104 . . . 98 . . . 88 Aqr (normal point)
ν Cap.	ι—ϵ Psc A.
	γ, ϵ, λ, κ, Cr A. (Lat. 30 S.).

Summer Zone

β Oph.	2 Lup.
δ Oph.	π Hya.
B 1113. North of μ Vir.	Inside β Cor.
Enclosing μ Ser.	Covering γ Cra.
12 Vir.	ν Hya.
β Leo. On the boundary of light.	Skirting Sextans.
ζ Leo. Covering the Sickle.	α Hya.
α Lyn.	" Vicinity of Procyon."

Zenith Width in Winter—
From γ Peg.
To η Cet.

Zenith Width in Summer—
Near γ Cor.
To ϵ Vir.

A NEW METHOD OF DETERMINING THE ATMOSPHERICAL EXTINCTION FACTOR IN PHOTO-ELECTRIC PHOTOMETRY.

W. M. Smart, M.A., D.Sc.

(Communicated by the Director, Cambridge Observatory)

1. In a previous paper * I described in detail three methods of evaluating the atmospherical extinction factor. The third method,† which has been chiefly used hitherto in our observations, depends on the principle that the performance of the photometer is constant from night to night, provided the voltage applied to the photo-electric cell remains unaltered. In practice this means that, for a given amount of radiation entering the photo-electric cell and for a given number of divisions of the photometer's scale, the observed time T is invariable and independent of the sensitivity of the instrument. For a star any variation in T then depends on the transparency of the atmosphere and on the star's zenith distance. It was shown that, provided the extinction factor could be determined on one or two nights by any other method, the time T for a star could be obtained for standard atmospherical conditions and for any zenith distance z; it was then a simple matter to deduce the extinction factor at any other time from the corresponding values of T and z.

2. In the method to be described the principle of instrumental invariability is still assumed, but it is now not necessary to have pre-determined values of the extinction factor on which to base the subsequent reductions.

Let f denote the extinction factor and T the corresponding time-measurement for a star at zenith distance z over a given number of scale divisions of the photometer. Let T_0 denote the time-measurement supposing the observation to be freed from the effect of the atmosphere. We then have ‡

$$\log \frac{T}{T_0} = \tfrac{2}{5} f \sec z, \tag{1}$$

or

$$\log T - x = \tfrac{2}{5} f \sec z, \tag{2}$$

where

$$x = \log T_0. \tag{3}$$

For a given non-variable star, T_0 (or x) is a constant.

The requisite observations consist in obtaining the simultaneous values

* *M.N.*, 94, 115, 1934. † See p. 123, § 7, *loc. cit.*

‡ See p. 121, formula (20), *loc. cit.* (All logarithms are to base 10.)

of T for two stars S_1 and S_2, usually separated in right ascension by 4 or 5 hours. We then have

$$\log T_1 - x_1 = \tfrac{2}{5} f \sec z_1, \tag{4}$$

$$\log T_2 - x_2 = \tfrac{2}{5} f \sec z_2, \tag{5}$$

in which it is tacitly assumed that the value of f is, at the time of observation, constant for all parts of the sky. Under favourable observational conditions it is unlikely that this assumption contains any germs of error, at least so far as Cambridge Observatory is concerned. The observatory is well to the north-west of the town and the river Cam, and unless the wind is from the south-east the differential effects of smoke or light mist in different directions in the sky have hitherto escaped detection. As regards observations of a variable star this particular problem does not arise, since the time-measurement of the comparison star (usually very close in the sky to the variable) contains the necessary information as to the particular value of f for that direction in the sky and at the time of observation.

Eliminate f from (4) and (5). Then

$$x_1 \cos z_1 - x_2 \cos z_2 = \cos z_1 \log T_1 - \cos z_2 \log T_2. \tag{6}$$

This is the fundamental equation on which the new method is based. Since it is an equation for x_1 and x_2 *which does not contain the extinction factor*, it can be combined with equations of the same form obtained on other occasions, irrespective of the state of the sky.

An hour or two later we shall have a similar equation with new values of z_1, z_2, T_1 and T_2, and, if the stars have been suitably chosen, the constants x_1 and x_2 can be fairly accurately determined. It is more satisfactory, however, to make observations on three or four nights in order to increase the weight of the solutions.

3. Let τ denote the time-measurement for zenith distance 0° and for the standard atmospherical extinction factor f_0. Then by (1)

$$\log \frac{\tau}{T_0} = \tfrac{2}{5} f_0, \tag{7}$$

or

$$\log \tau - x = \tfrac{2}{5} f_0, \tag{8}$$

in which x is now supposed known from the solution of several equations of condition of the form (6). I take the standard value of f_0 to be 0·4 on the usual magnitude scale. Hence, from (8), the standard time-measurement for the zenith is obtained. *We regard the values of τ for several selected stars as the foundation on which the present method of deriving the extinction factor is based.*

From (2) and (8) we have, by eliminating x,

$$f = \tfrac{5}{2} \cos z \log \frac{T}{\tau} + f_0 \cos z. \tag{9}$$

Knowing τ and z and observing T, we obtain from this formula the value of f at the time of observation.

The ratio T/τ ($\equiv r$) is most conveniently obtained by a graphical method. With τ as abscissa and T as ordinate, the straight lines $T/\tau =$ constant are drawn for $r = 0{\cdot}9$, $1{\cdot}0$, $1{\cdot}1$, etc. ; for any given τ and observed T it is easy to obtain by inspection the corresponding value of r. In practice it is sufficient to determine r with an accuracy of $0{\cdot}01$.

The value of z is obtained from a curve exhibiting the zenith distance as a function of the sidereal time.

Table I gives the values of f, corresponding to different values of T/τ and z, calculated from formula (9). Values less than $0{\cdot}15$ and greater than $1{\cdot}00$ are not inserted.

TABLE I

Values of f

z \ T/τ	0·8	0·9	1·0	1·1	1·2	1·3	1·4	1·5	1·6	1·7	1·8	1·9	2·0
0	0·16	0·29	0·40	0·50	0·60	0·68	0·76	0·84	0·91	0·98	...	...	...
5	0·16	0·29	0·40	0·50	0·60	0·68	0·76	0·84	0·91	0·97	...	...	...
10	0·16	0·28	0·39	0·50	0·59	0·67	0·75	0·83	0·90	0·96	...	...	...
15	0·16	0·28	0·39	0·49	0·58	0·66	0·74	0·81	0·88	0·94	1·00	...	...
20	0·15	0·27	0·38	0·47	0·56	0·64	0·72	0·79	0·86	0·92	0·97	...	...
25	...	0·26	0·37	0·45	0·54	0·62	0·70	0·76	0·83	0·88	0·94	0·99	...
30	...	0·25	0·35	0·43	0·52	0·59	0·67	0·73	0·79	0·84	0·90	0·95	1·00
35	...	0·23	0·33	0·41	0·49	0·56	0·63	0·69	0·75	0·80	0·85	0·90	0·94
40	...	0·22	0·31	0·38	0·46	0·52	0·59	0·64	0·70	0·75	0·79	0·84	0·88
45	...	0·20	0·28	0·35	0·42	0·49	0·54	0·59	0·64	0·69	0·73	0·78	0·82
50	...	0·18	0·26	0·32	0·38	0·44	0·49	0·54	0·58	0·63	0·67	0·71	0·74
55	...	0·16	0·23	0·29	0·34	0·40	0·44	0·48	0·52	0·56	0·60	0·63	0·66
60	...	...	0·20	0·25	0·30	0·34	0·38	0·42	0·46	0·49	0·52	0·55	0·58
65	...	...	0·17	0·21	0·25	0·29	0·32	0·36	0·38	0·41	0·44	0·44	0·49
70	...	...	...	0·17	0·20	0·23	0·26	0·29	0·31	0·34	0·36	0·38	0·40

Fig. 1 is the graphical representation of Table I, showing the curves $r \equiv T/\tau =$ constant, for $r = 0{\cdot}9$, $1{\cdot}0$, $1{\cdot}1$, . . ., $1{\cdot}8$, with the zenith distance z as abscissa and f as ordinate. Hence for given values of T/τ and z the corresponding value of f can be found at once by inspection.

4. The method can be tested readily by deriving the *true* difference of magnitude of two stars of constant brightness, the observations of which provide equations of condition of the form (6).

If m_1, m_2 denote the observed magnitudes of the stars on any night and M_1, M_2 their true magnitudes (corresponding to hypothetical observations outside the terrestrial atmosphere), we have

$$\left.\begin{aligned} m_1 &= M_1 + f \sec z_1 \\ m_2 &= M_2 + f \sec z_2 \end{aligned}\right\}. \tag{10}$$

If Δm, ΔM denote $m_2 - m_1$, $M_2 - M_1$, then

$$\Delta M = \Delta m + fF, \tag{11}$$

where

$$F = \sec z_1 - \sec z_2. \tag{12}$$

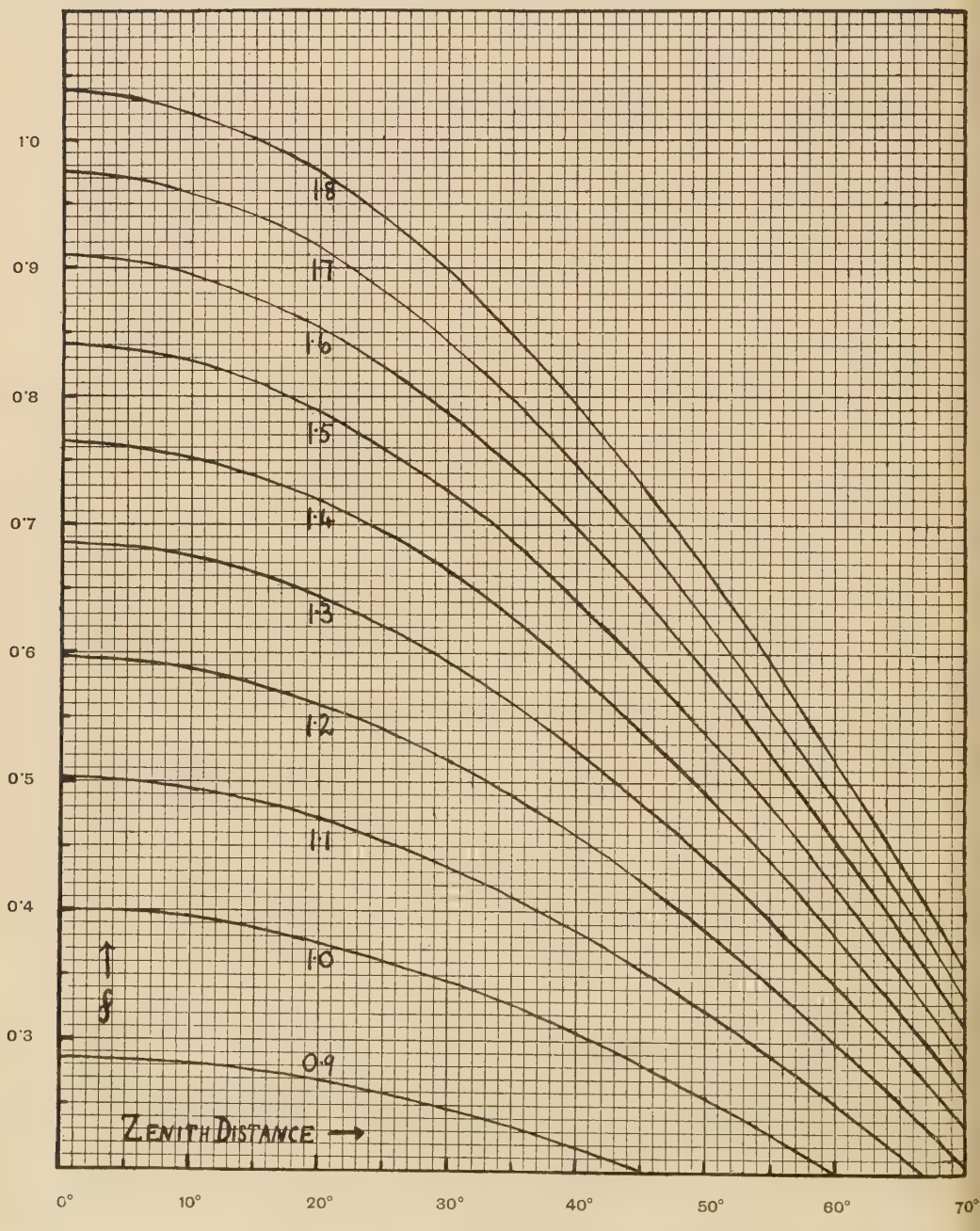


FIG. 1.—*Curves* $r(\equiv T/\tau) = constant$, *with Zenith Distance as abscissa and* f *as ordinate.*

The photometer measures Δm. If T_1 and T_2 are the corresponding time-measurements over the same number of divisions of the scale, Δm is found from the formula

$$\Delta m = \tfrac{5}{2} \log \frac{T_2}{T_1}. \qquad (13)$$

When we know the appropriate value of f, the true difference of magnitude, ΔM, can be easily calculated by means of (11).

5. We shall illustrate and test the method from observations of the pair of Ao stars, α Cor. Bor. and β Urs. Maj., on four nights mostly of good seeing, and from observations of the pair of Ao stars, 12^2 Can. Ven. and o Her., on three nights when the seeing was poor.

TABLE II

Observations of α Cor. Bor. and β Urs. Maj.

Date	Sid. Time	α Cor. Bor.		β Urs. Maj.		Δm
		T_1	z_1	T_2	z_2	
	h m	s	°	s	°	
1934 May 10	12 48	14·38	39·4	14·49	16·4	+0·008
	14 56	13·11	26·2	15·19	33·7	+0·160
May 14	12 44	18·32	40·2	17·44	15·5	−0·054
	14 56	13·83	26·2	15·79	33·8	+0·144
May 17	13 21	12·49	35·1	13·18	21·0	+0·059
May 18	13 8	13·61	36·8	13·76	19·3	+0·012
	13 50	13·24	31·6	14·14	24·9	+0·071

Each star was observed over 10 divisions of the scale. The entries in the last column are calculated by means of (13) from the corresponding values of T_1 and T_2.

The table provides the data for seven equations of condition of the form (6). These equations were solved by least squares. Much of the arithmetical labour can be avoided, if observing conditions permit, by observing the stars at two definite sidereal times, about two hours apart, and grouping together all the equations at each of the two epochs of observation. In this way two pseudo-normal equations are formed.

The solutions are:

$$x_1(\alpha \text{ Cor. Bor.}) = 0{\cdot}9397,$$
$$x_2(\beta \text{ Urs. Maj.}) = 0{\cdot}9822,$$

corresponding, in each instance, to 10 divisions of the scale.* The true difference of magnitude for this pair is $\frac{5}{2}(x_2 - x_1)$ or $0^m{\cdot}106$. The Harvard visual magnitudes are 2·31 and 2·44, giving a difference of $0^m{\cdot}13$.

From formula (8) the values of τ (the time-measurement for zenith distance 0° and standard extinction factor $f_0 = 0{\cdot}4$) are easily found. They are (to the nearest $0^s{\cdot}1$):

$$\tau_1(\alpha \text{ Cor. Bor.}) = 12^s{\cdot}6,$$
$$\tau_2(\beta \text{ Urs. Maj.}) = 13^s{\cdot}9,$$

for 10 divisions of the scale.

* Actually it is much more convenient, as regards the arithmetical calculations, to use $T_1/10$ and $T_2/10$ instead of T_1 and T_2.

The further reductions are shown in Table III.

TABLE III

Reductions of Observations of α Cor. Bor. and β Urs. Maj.

Date	r_1	r_2	f		F	ΔM
			α Cor. Bor.	β Urs. Maj.		
1934 May 10	1·14	1·05	0·42	0·43	+0·252	0·115
	1·04	1·09	0·40	0·41	−0·087	0·125
May 14	1·46	1·26	0·62	0·62	+0·264	0·110
	1·10	1·14	0·45	0·45	−0·089	0·104
May 17	1·00	0·95	0·33	0·32	+0·151	0·108
May 18	1·08	0·99	0·38	0·37	+0·189	0·084
	1·05	1·02	0·38	0·39	+0·069	0·097

The second column contains the values of the ratio $r_1 \equiv T_1/\tau_1$ for α Cor. Bor., the values of T_1 being found in Table II, column 3. The third column gives the corresponding ratios for β Urs. Maj. Each star furnishes a value of the extinction factor, derived from Table I or more easily from fig. 1, using the now known values of r_1, z_1 and of r_2, z_2. These values of f are shown in columns 4 and 5 of Table III, and they are in excellent agreement at each epoch of observation. Column 6 contains the values of F calculated by means of (12). The next column contains the true difference of magnitude of the two stars calculated for each epoch of observation by means of formula (11), the values of Δm being found in the last column of Table II; the value of f used in this calculation is the mean of the values given by the two stars (columns 4 and 5 of Table III).

From the seven determinations of ΔM we obtain

$$\Delta M = 0^{m}\cdot 106 \pm 0^{m}\cdot 008.$$

As only a single determination of the magnitude difference Δm was made at each of the epochs of observation, the probable error may be considered satisfactorily small.

6. Tables IV and V give similar details for the pair of Ao stars 12^2 Can. Ven. and o Her. on three nights of indifferent seeing, observations of the first star being taken over 10 divisions of the scale and observations of the second over 5 divisions.

TABLE IV

Observations of 12^2 Can. Ven. and o Her.

Date	Sid. Time	12^2 Can. Ven.		o Her.		Δm
		T_1	z_1	T_2	z_2	
	h m	s	°	s	°	
1934 May 30	14 18	24·20	20·0	40·72	47·7	1·317
	17 15	35·70	46·0	38·00	25·3	0·820
May 31	16 53	29·68	42·8	34·84	27·0	0·928
June 12	15 23	25·23	29·1	36·02	38·1	1·139
	17 27	34·68	48·0	36·66	24·7	0·813

The second observation on May 30 was a poor one; in the sequel it is given half-weight. The solution of the five equations of condition of the form (6) gives

$$x_1 = 1{\cdot}1395,$$
$$x_2 = 1{\cdot}2668,$$

from which the true difference of magnitude ΔM of the stars is

$$\tfrac{5}{2}(x_2 - x_1) + \tfrac{5}{2}\log 2 \quad \text{or} \quad 1^{\mathrm{m}}{\cdot}071,$$

the term $\frac{5}{2}\log 2$ being introduced on account of the different number of scale divisions over which the observations were made. The Harvard visual magnitudes are 2·90 and 3·83, giving a difference of $0^{\mathrm{m}}{\cdot}93$.

The corresponding values of τ_1 and τ_2 are:

$$\tau_1(12^2 \text{ Can. Ven., } 10 \text{ divisions}) = 19^{\mathrm{s}}{\cdot}9,$$
$$\tau_2(o \text{ Her., } \quad 5 \quad ,, \quad) = 26^{\mathrm{s}}{\cdot}7.$$

TABLE V

Reduction of Observations of 12^2 Can. Ven. and o Her.

Date	r_1	r_2	f		F	ΔM
			12^2 Can. Ven.	*o* Her.		
1934 May 30	1·22	1·52	0·58	0·57	−0·422	1·074
	1·79	1·42	0·72	0·71	+0·333	1·057
May 31	1·49	1·30	0·61	0·61	+0·241	1·075
June 12	1·27	1·35	0·57	0·57	−0·126	1·068
	1·74	1·37	0·67	0·68	+0·394	1·078

From the five determinations of ΔM we obtain, giving half-weight to the second observation on May 30,

$$\Delta M = 1^{\mathrm{m}}{\cdot}070 \pm 0^{\mathrm{m}}{\cdot}004.$$

Considering the poorness of the seeing, the probable error is very small; this is partly to be accounted for by the fact that, at each of three of the epochs of observation, two determinations of Δm were made.

7. So far as the application of this method to photometric measures of variable stars is concerned, the chief requisite is the value of τ for the comparison star, for if τ is known the value of the extinction factor at any time can be rapidly deduced from fig. 1, as is illustrated in the two preceding sections. There is a certain economy of observational and computational effort if the comparison star is chosen as one of the pair of stars necessary for the application of the method, but this desideratum is not essential; nor is it always possible, especially when several variables with much the same right ascension are under observation. The procedure in practice is simply to deduce τ, for the comparison star, by means of fig. 1 on a night when the extinction factor f is known from the measures of the pair of stars

observed specially for the determination of f. A modification of the procedure is to make a single determination of Δm for the pairs of stars and, ΔM being assumed known—its value is supposed to have been found as in the examples of the two preceding sections—f is readily calculated from (11). The value of τ for the comparison star is then obtained by means of fig. 1. It is to be noted, however, that, in using (11) for this purpose, the numerical value of F should be at least 0·3 or 0·4.

There is one further point to notice. If the photometer is attached to a reflecting telescope or to a coudé instrument in which a silvered mirror forms part of the optical train, the value of τ for a given star increases with loss of reflecting power of the mirror. It is then necessary to make determinations of τ at intervals of about a month. In this respect the advantage of the refractor over the reflecting and coudé instruments is evident. This advantage, however, will disappear if the claims made for aluminium-coated mirrors, as regards constancy of reflecting power over considerable intervals of time, are justified by experience. A technical development of this nature will prove specially advantageous in photo-electric photometry with reflecting and coudé telescopes.

Observatory, Cambridge :
1934 *August* 15.

THE LIGHT-VARIATION OF V22 = SV ANDROMEDÆ.

J. van der Bilt, Ph.D.

1. The long-period variable SV Andromedæ was discovered early in 1907 by Mme. Ceraski. Photographic estimates by Blažko on plates taken between 1904 and 1906, and a small number of visual estimates by Pračka (1907–1909) and Miss Furness (1908–1912), revealed its long periodical character and the fact that the maximum brightness was fluctuating to a rather large extent.

Systematic observations were started in 1912 by the observers of the American Association of Variable Star Observers (A.A.V.S.O.) and by the writer, and in 1917 by Mr. C. F. Butterworth of Port St. Mary, Isle of Man. It is largely due to the uninterrupted and accurate work of the latter that the detailed study of the star's light-variation can be presented in the present paper.

From the list of A.A.V.S.O. observers I have omitted the names of those who have contributed only a single observation. As to the others I consider it a matter of courtesy not to treat them anonymously, but to give a list of their names and particulars about their instruments; especially since it appears that the mean deviation of the estimates of these observers (taken as a group) from the final light-curve does not differ appreciably from that of my own estimates.

TABLE I

List of A.A.V.S.O. Observers

Abbr.	Name	Residence	Instrument
An	H. Ancanari	Faenza, Italy	3″ refr., 8″ refl.
B	T. C. H. Bouton	St. Petersbg., Fla. ; Hudson, N.H.	6″ refr., 7″ refl.
Ba	H. C. Bancroft	W. Collingswood, N.J.	5″ refr.
Be	D. Benini	Faenza, Italy	3″ refr., 8″ refl.
Bi	L. Berman	Minneapolis, Minn.	15″ refr.
Br	D. F. Brocchi	Seattle, Wash.	10″ refl.
Bw	H. W. Bigelow	Northampton, Mass.	3″ refr., 11″ refr.
Ch	R. G. Chandra	Bagchar Jessore, Br. India	3″ refr., 6″ refr.
Cy	M. Cilley	Brooklyn, N.Y. ; Romney, Va.	5½″ refl.
De	W. J. Delmhorst	Jersey City, N.J.	4″ refr.
Hu	W. Houston	Madison, Wisc.	4″ refr.
Ie	N. Iedema	Great Neck, Long Island, N.Y.	10″ refl.
Jk	Miss L. Jenkins	Mt. Holyoke Coll., So. Hadley, Mass.	8″ refr.
Jo	E. H. Jones	Somerville, Mass. ; Goffstown, N.H.	3, 5 and 6″ refr.
Kz	C. Kurtz	Bethlehem, Pa.	11″ refl.
Lg	J. H. Logan	New York City ; Dallas, Tex.	3, 4 and 12″ refr.
Lv	F. P. Leavenworth	Minneapolis, Minn.	15″ refr.
M	C. Y. McAteer	Pittsburgh, Pa.	4″ refr., 5″ refr.
Md	R. E. Millard	Portland, Oregon	4″ refr.
Mg	O. E. Monnig	Fort Worth, Tex.	4″ refr., 11″ refl.
Pi	D. B. Pickering	East Orange, N.J.	3½″ refr., 5″ refr.
Pt	L. C. Peltier	Delphos, Ohio	2, 4 and 6″ refr.
Y	A. S. Young	Mt. Holyoke Coll., So. Hadley, Mass.	8″ refr.

2. The material from which I have derived a homogeneous and fairly continuous representation of the star's behaviour between 1912 and 1934 consists of the following observations :—

Name	Instrument	Number of Observations	Reference
Butterworth	6″ refr.	783	*Bull. Lyon ; Bull. Ass. Fr. Obs. Etoiles var.*
A.A.V.S.O.	Various instruments	461	*P.A.* (various vols.).
van der Bilt	3″, 4½″ and 10″ refr.	214	*J.d.O.*, 15, 118.

The total number of observations is 1458, embracing an interval of 7985 days. There is a gap of 195 days between J.D. 241 9484 and 241 9679. From the latter date on the observations are continuous ; this is shown by Table II, which contains for 10 consecutive intervals of about two years the total number of observations (n) and the mean frequency (m) per 30 days.

The number of observations per month, required for a reliable light-curve of a 300 days' period, may be considered to be 3 or 4. In Table II the mean value of m is 5·7 ; that is to say, the points are evenly distributed

in a more than sufficient density. It is again only fair to state that this result is almost entirely due to Mr. Butterworth; his 783 observations nearly continuously cover 6142 days, and for him alone the mean value of m is already 3·8.

TABLE II

Mean Number of Observations per Month

Interval	n	m	Interval	n	m
J.D. 9680–0459	67	2·6	J.D. 3580–4359	163	6·3
0460–1239	59	2·3	4360–5139	143	5·5
1240–2019	164	6·3	5140–5919	178	6·8
2020–2799	156	6·0	5920–6699	166	6·4
2800–3579	129	5·0	6700–7419	225	9·4

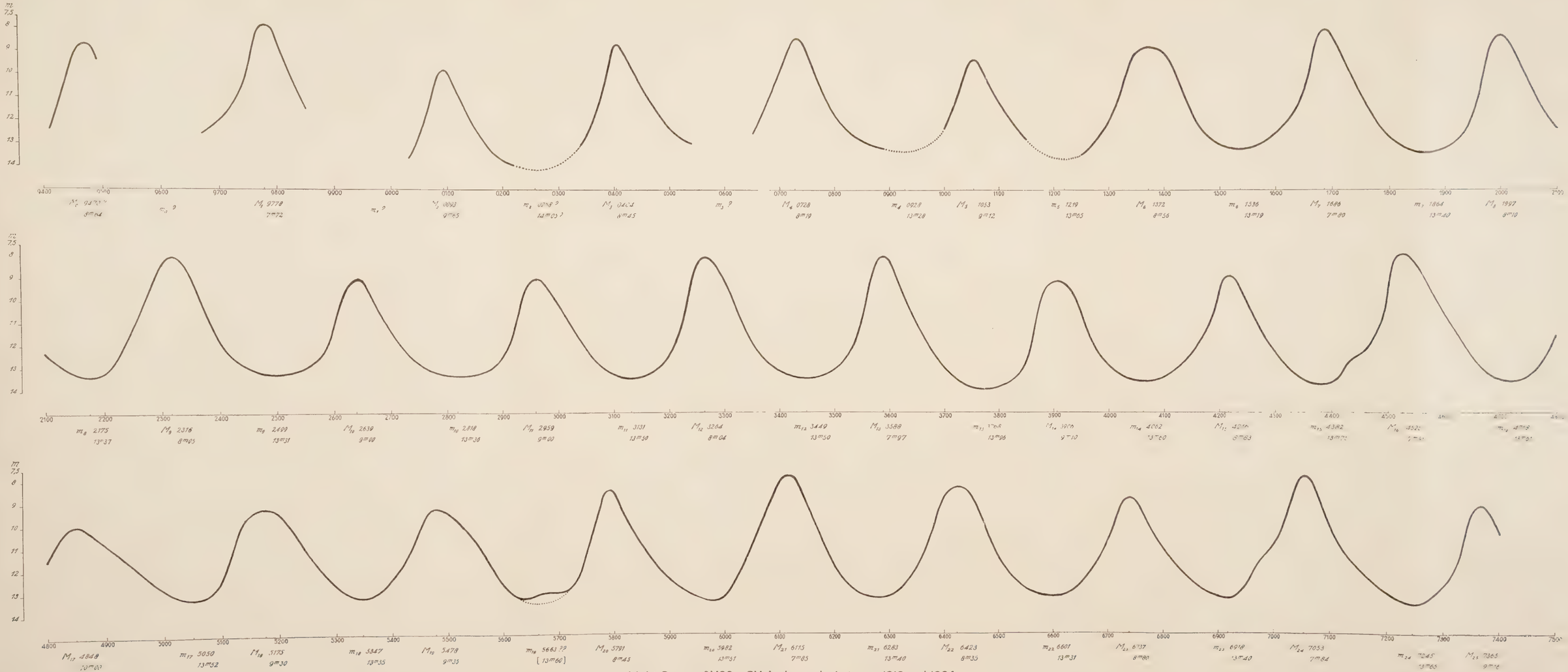
3. I have drawn a provisional light-curve using only Butterworth's (Bu's) observations. After the rejection of 14 observations of other observers, which deviated more than $0^m.70$ from the curve, I have tabulated the residuals of the estimates of all the other observers. As I had anticipated, these were partly dependent on the star's brightness. Table III gives the results for the first of these groups; the abbreviations for the names of the observers are the same as in Table I.

TABLE III

Reductions to Bu, dependent on Magnitude

Magn.	Br	Bw	Hu	Lg	Lv
m	m	m	m	m	m
8·0	...	...	+·32	+·60	...
8·5	...	+·15	+·30	+·53	...
9·0	...	−·01	+·26	...	...
9·5	+·19	−·18	+·19	...	+·10
10·0	+·07	−·31	+·10	...	+·02
10·5	−·05	−·42	−·01	...	−·01
11·0	−·16	−·46	−·15	...	−·01
11·5	−·21	−·40	−·29	...	+·01
12·0	−·13	−·24	−·45	...	+·07
12·5	00	−·07	−·62	...	+·15
13·0	+·21	+·14	−·82	+·05	+·28
13·5	+·40	...	...	−·02	+·45

The results for the second group are given in Table IV. The first tabulated column contains the constant reduction to be applied to an observation of the observer of col. 1; then follow the mean error of this amount and the percentage of residuals less than $0^m.40$. The results for Be, De, Kz, Md and Mg being uncertain, I have inserted the corresponding values between brackets. Bl stands for the writer's name.



Light-Curve of V22 = SV Andromedæ between 1912 and 1934.

J. van der Bilt, Light-variation of SV Andromedæ.

TABLE IV

Reductions to Bu, independent of Magnitude

Obs.	Red.	m.e.	$<^{m}.40$ %	Obs.	Red.	m.e.	$<^{m}.40$ %
	m	m			m	m	
An	−·27	·18	80	Ie	−·31	·06	100
B	00	·05	82	Jk	−·30	·24	60
Ba	+·32	·13	60	Jo	00	·25	87
Be	[+·28]	...	...	Kz	[+·08]	...	...
Bi	00	·08	80	M	+·11	·03	100
Bl 10	−·03	·01	77	Md	[+·18]	...	...
,, $4\frac{1}{2}$	−·27	·03	70	Mg	[+·07]	...	...
,, 3	−·30	·03	92	Pi	−·09	·09	70
Ch	−·13	·13	80	Pt	00	·02	80
Cy	−·19	·15	78	Y	−·05	·06	79
De	[−·16]	...	...				

After having applied the reductions of the Tables III and IV, I have drawn a definitive light-curve which may be considered to represent the star's behaviour between 1912 and 1934, as if Mr. Butterworth were responsible for all the observations. It is, however, not a true representation, since the personality of the observer could not be eliminated, *nor that of the observer who is responsible for the magnitudes of the comparison stars.* This is a serious point, especially in this case, since the chief observer (Bu) used the decimal method; for this implies that the Harvard magnitudes of the comparison stars must be adopted as they stand.

Now, the Harvard sequence gives the magnitudes of the three faintest comparison stars as $12^{m}.70$, $12^{m}.88$ and $13^{m}.06$ respectively. My own estimates with the 10-in. refractor, while generally agreeing with the magnitudes of the brighter stars, make those of the three faintest stars $13^{m}.08$, $13^{m}.42$ and $13^{m}.80$. The differences are $0^{m}.38$, $0^{m}.54$ and $0^{m}.72$.

Miss Furness, in *Publ. Vassar Coll. Obs.*, No. 3, p. 199, also gives the faintest star the brightness $13^{m}.80$. The lower parts of my light-curve, therefore, may be systematically in error from about $12^{m}.3$ on, and with an amount increasing downwards. It will, of course, be possible to correct the error as soon as a redetermination of the magnitudes of these faint stars might point to the necessity thereof.

4. The light-curve is shown on Plate 7. A study of the residuals from this curve has yielded the following results :—

Butterworth	mean resid.	$0^{m}.139$.
A.A.V.S.O.	,, ,,	·206.
van der Bilt (10″)	,, ,,	·199.
,, ,, ($4\frac{1}{2}$″)	,, ,,	·196.
,, ,, (3″)	,, ,,	·211.

The magnitude of the variable has been taken from the curve in intervals of 10 days. These values are given in Table V (interpolated values between brackets); they will allow anyone wishing to make a close analysis of the

light-variation to trace the curve on any desired scale. The original estimates will be kept at the Utrecht Observatory and are at the disposal of investigators.

TABLE V

Light-curve of V_{22}=SV Andromedæ.

J.D.	M.	J.D.	M.	J.D.	M.	J.D.	M.	J.D.	M.
	m		m		m		m		m
241 9410	12·40	242 0260	[14·10]	242 0780	10·77	242 1300	11·85	242 1820	13·06
20	11·67	70	[14·09]	90	11·22	10	11·33	30	13·20
30	10·85	80	[14·06]	0800	11·63	20	10·73	40	13·31
40	10·06	90	[13·92]	10	11·98	30	9·92	50	13·35
50	9·32	0300	[13·81]	20	12·24	40	9·12	60	13·39
60	8·78	10	[13·68]	30	12·47	50	8·75	70	13·39
70	8·64	20	[13·52]	40	12·64	60	8·61	80	13·34
80	8·77	30	[13·30]	50	12·77	70	8·56	90	13·27
90	9·36	40	13·00	60	12·90	80	8·59	1900	13·18
—	—	50	12·45	70	13·01	90	8·67	10	13·02
9670	12·57	60	11·99	80	13·10	1400	8·87	20	12·81
80	12·38	70	11·28	90	13·15	10	9·23	30	12·52
90	12·16	80	10·43	0900	[13·23]	20	9·75	40	12·10
9700	11·94	90	9·50	10	[13·26]	30	10·38	50	11·56
10	11·66	0400	8·52	20	[13·30]	40	10·96	60	10·63
20	11·31	10	8·60	30	[13·30]	50	11·47	70	9·33
30	10·90	20	9·05	40	[13·27]	60	11·94	80	8·54
40	10·36	30	9·55	50	[13·20]	70	12·32	90	8·17
50	9·40	40	10·00	60	[13·09]	80	12·57	2000	8·11
60	8·27	50	10·45	70	[12·96]	90	12·79	10	8·34
70	7·80	60	10·85	80	[12·80]	1500	12·96	20	8·83
80	7·72	70	11·25	90	[12·57]	10	13·06	30	9·41
90	7·90	80	11·61	1000	12·25	20	13·13	40	9·92
9800	8·56	90	11·95	10	11·62	30	13·16	50	10·37
10	9·22	0500	12·24	20	10·85	40	13·16	60	10·80
20	9·82	10	12·49	30	10·10	50	13·13	70	11·24
30	10·36	20	12·67	40	9·47	60	13·06	80	11·62
40	10·90	30	12·83	50	9·13	70	12·95	90	11·98
50	11·46	40	12·94	60	9·21	80	12·84	2100	12·30
242 0030	13·63	50	...	70	9·67	90	12·65	10	12·56
40	13·17	60	...	80	10·22	1600	12·45	20	12·78
50	12·55	70	...	90	10·69	10	12·21	30	12·96
60	11·82	80	...	1100	11·10	20	11·95	40	13·11
70	11·07	90	...	10	11·48	30	11·57	50	13·25
80	10·12	0600	...	20	11·85	40	11·12	60	13·34
90	9·67	10	...	30	12·18	50	10·50	70	13·36
0100	9·80	20	...	40	12·47	60	9·56	80	13·36
10	10·39	30	...	50	12·70	70	8·40	90	13·34
20	10·84	40	...	60	[12·98]	80	7·85	2200	13·24
30	11·32	50	12·50	70	[13·18]	90	7·81	10	13·02
40	11·82	60	12·01	80	[13·33]	1700	8·15	20	12·66
50	12·30	70	11·40	90	[13·46]	10	8·70	30	12·17
60	12·68	80	10·82	1200	[13·56]	20	9·22	40	11·68
70	13·03	90	10·20	10	[13·60]	30	9·76	50	11·20
80	13·30	0700	9·56	20	[13·65]	40	10·29	60	10·94
90	13·52	10	8·90	30	[13·61]	50	10·76	70	10·62
0200	13·70	20	8·35	40	[13·55]	60	11·22	80	9·75
10	13·83	30	8·20	50	13·42	70	11·66	90	8·84
20	13·94	40	8·43	60	13·22	80	12·06	2300	8·33
30	[14·00]	50	9·01	70	12·98	90	12·42	10	8·08
40	[14·05]	60	9·60	80	12·69	1800	12·61	20	8·06
50	[14·09]	70	10·26	90	12·32	10	12·86	30	8·22

J.D.	M.	J.D.	M.	J.D.	M.	J.D.	M.	J.D.	M.
	m		m		m		m		m
242 2340	8·60	242 2910	11·99	242 3480	13·35	242 4050	13·59	242 4620	11·42
50	9·08	20	11·21	90	13·21	60	13·60	30	11·80
60	9·66	30	10·30	3500	13·04	70	13·59	40	12·16
70	10·21	40	9·50	10	12·84	80	13·57	50	12·52
80	10·82	50	9·08	20	12·55	90	13·50	60	12·81
90	11·35	60	9·00	30	12·21	4100	13·37	70	13·07
2400	11·84	70	9·10	40	11·61	10	13·25	80	13·28
10	12·19	80	9·46	50	10·73	20	13·07	90	13·45
20	12·46	90	9·85	60	9·60	30	12·90	4700	13·55
30	12·68	3000	10·22	70	8·67	40	12·67	10	13·60
40	12·85	10	10·62	80	8·05	50	12·38	20	13·61
50	12·97	20	11·02	90	8·00	60	12·02	30	13·59
60	13·10	30	11·44	3600	8·23	70	11·59	40	13·50
70	13·17	40	11·78	10	8·82	80	11·15	50	13·35
80	13·24	50	12·15	20	9·40	90	10·44	60	13·12
90	13·28	60	12·46	30	9·94	4200	9·43	70	12·84
2500	13·31	70	12·76	40	10·49	10	8·87	80	12·47
10	13·28	80	13·00	50	11·05	20	8·85	90	12·09
20	13·25	90	13·16	60	11·56	30	9·07	4800	11·55
30	13·20	3100	13·30	70	12·02	40	9·61	10	11·13
40	13·11	10	13·40	80	12·40	50	10·11	20	10·73
50	13·01	20	13·45	90	12·73	60	10·65	30	10·30
60	12·85	30	13·50	3700	13·03	70	11·10	40	10·04
70	12·67	40	13·46	10	13·27	80	11·52	50	10·00
80	12·40	50	13·41	20	13·47	90	11·95	60	10·08
90	11·90	60	13·31	30	13·65	4300	12·29	70	10·25
2600	11·03	70	13·17	40	13·80	10	12·67	80	10·45
10	10·22	80	12·97	50	13·90	20	12·98	90	10·64
20	9·55	90	12·72	60	13·94	30	13·21	4900	10·85
30	9·12	3200	12·35	70	13·96	40	13·43	10	11·07
40	9·00	10	11·90	80	13·95	50	13·57	20	11·28
50	9·15	20	11·28	90	13·90	60	13·65	30	11·50
60	9·56	30	10·32	3800	13·82	70	13·72	40	11·71
70	10·08	40	9·10	10	13·71	80	13·75	50	11·92
80	10·53	50	8·29	20	13·58	90	13·71	60	12·14
90	11·00	60	8·05	30	13·42	4400	13·65	70	12·37
2700	11·43	70	8·06	40	13·16	10	13·50	80	12·58
10	11·77	80	8·30	50	12·70	20	13·09	90	12·75
20	12·11	90	8·65	60	11·70	30	12·77	5000	12·92
30	12·40	3300	9·14	70	10·58	40	12·58	10	13·06
40	12·65	10	9·66	80	9·70	50	12·41	20	13·17
50	12·83	20	10·26	90	9·25	60	12·22	30	13·26
60	12·99	30	10·88	3900	9·11	70	11·90	40	13·30
70	13·11	40	11·43	10	9·11	80	11·44	50	13·32
80	13·22	50	11·95	20	9·22	90	10·80	60	13·30
90	13·30	60	12·32	30	9·52	4500	9·35	70	13·25
2800	13·35	70	12·60	40	9·95	10	8·15	80	13·12
10	13·35	80	12·82	50	10·50	20	7·87	90	12·89
20	13·36	90	13·01	60	11·25	30	7·86	5100	12·49
30	13·35	3400	13·14	70	11·81	40	8·08	10	11·82
40	13·32	10	13·27	80	12·26	50	8·47	20	11·05
50	13·26	20	13·37	90	12·61	60	8·85	30	10·28
60	13·20	30	13·45	4000	12·90	70	9·27	40	9·81
70	13·10	40	13·49	10	13·11	80	9·71	50	9·55
80	13·00	50	13·50	20	13·31	90	10·15	60	9·40
90	12·80	60	13·47	30	13·45	4600	10·56	70	9·31
2900	12·52	70	13·43	40	13·55	10	11·00	80	9·31

J.D.	M.	J.D.	M.	J.D.	M.	J.D.	M.	J.D.	M.
	m		m		m		m		m
242 5190	9·35	242 5640	13·34	242 6090	8·54	242 6540	12·72	242 6990	11·25
5200	9·52	50	13·30	6100	8·10	50	12·92	7000	10·92
10	9·82	60	13·20	10	7·89	60	13·07	10	10·50
20	10·14	70	13·14	20	7·86	70	13·19	20	9·87
30	10·50	80	13·12	30	8·08	80	13·26	30	9·00
40	10·95	90	13·12	40	8·62	90	13·30	40	8·21
50	11·30	5700	13·11	50	9·25	6600	13·31	50	7·87
60	11·63	10	13·04	60	9·75	10	13·30	60	7·91
70	11·94	20	12·92	70	10·30	20	13·26	70	8·30
80	12·25	30	12·70	80	10·91	30	13·14	80	8·91
90	12·52	40	12·23	90	11·49	40	12·98	90	9·60
5300	12·77	50	11·37	6200	11·92	50	12·76	7100	10·25
10	12·98	60	10·50	10	12·32	60	12·45	10	10·77
20	13·12	70	9·64	20	12·64	70	12·12	20	11·15
30	13·25	80	8·72	30	12·89	80	11·75	30	11·47
40	13·32	90	8·45	40	13·07	90	11·30	40	11·77
50	13·34	5800	8·66	50	13·21	6700	10·77	50	12·08
60	13·30	10	9·22	60	13·30	10	10·18	60	12·31
70	13·21	20	9·70	70	13·36	20	9·31	70	12·56
80	13·02	30	10·16	80	13·39	30	8·93	80	12·78
90	12·71	40	10·57	90	13·38	40	8·80	90	12·98
5400	12·43	50	10·95	6300	13·32	50	9·00	7200	13·16
10	12·13	60	11·35	10	13·16	60	9·44	10	13·32
20	11·75	70	11·70	20	13·00	70	9·90	20	13·48
30	11·36	80	12·02	30	12·74	80	10·37	30	13·59
40	10·89	90	12·26	40	12·42	90	10·78	40	13·64
50	10·25	5900	12·48	50	12·04	6800	11·15	50	13·64
60	9·64	10	12·71	60	11·46	10	11·47	60	13·58
70	9·41	20	12·87	70	10·92	20	11·78	70	13·43
80	9·36	30	13·04	80	10·20	30	12·06	80	13·25
90	9·41	40	13·18	90	9·40	40	12·32	90	13·03
5500	9·55	50	13·32	6400	8·77	50	12·55	7300	12·76
10	9·73	60	13·43	10	8·46	60	12·76	10	12·45
20	9·94	70	13·50	20	8·35	70	12·97	20	11·97
30	10·21	80	13·51	30	8·36	80	13·09	30	11·25
40	10·49	90	13·47	40	8·50	90	13·20	40	10·26
50	10·79	6000	13·33	50	8·85	6900	13·30	50	9·56
60	11·16	10	13·03	60	9·30	10	13·37	60	9·19
70	11·54	20	12·60	70	9·88	20	13·40	70	9·19
80	11·96	30	12·10	80	10·47	30	13·33	80	9·52
90	12·37	40	11·55	90	11·03	40	13·10	90	9·95
5600	12·73	50	10·97	6500	11·52	50	12·76	7400	10·47
10	13·02	60	10·40	10	11·90	60	12·33		
20	13·22	70	9·74	20	12·26	70	11·90		
30	13·31	80	9·11	30	12·51	80	11·52		

5. The dates of maximum and minimum brightness, together with the magnitudes and the intervals between successive maxima and minima, have been collected in Table VI. The uncertainty in the dates is about 2^d for the maxima and 4^d for the minima (mean values); that of the maximum brightness is generally below $0^m.05$ and always below $0^m.1$. The brightness of a minimum may, in some cases, be a little more uncertain.

TABLE VI

Maxima and Minima of SV Andromedæ.

No.	Maximum	M.	Interval	No.	Minimum	M.	Interval
		m	d				
0	241 9470	8·64		0			
1	9778	7·72	308	1		m	
2	242 0093	9·65	315	2	242 0260?	14·10?	
3	0404	8·45	311	3	?	13·22?	
4	0728	8·19	324	4	0928	13·30	d
5	1053	9·12	325	5	1219	13·65	291
6	1372	8·56	319	6	1536	13·19	317
7	1686	7·80	314	7	1864	13·40	328
8	1997	8·10	311	8	2175	13·37	311
9	2316	8·05	319	9	2499	13·31	324
10	2639	9·00	323	10	2818	13·36	319
11	2959	9·00	320	11	3131	13·50	313
12	3264	8·04	305	12	3449	13·50	318
13	3588	7·97	324	13	3768	13·96	319
14	3906	9·10	318	14	4062	13·60	294
15	4216	8·83	310	15	4382	13·75	320
16	4525	7·85	309	16	4718	13·61	336
17	4848	10·00	323	17	5050	13·52	332
18	5175	9·30	327	18	5347	13·35	297
19	5478	9·35	303	19	5663	13·60	316
20	5791	8·45	313	20	5982	13·51	319
21	6115	7·85	324	21	6283	13·40	301
22	6423	8·35	308	22	6601	13·31	318
23	6739	8·80	316	23	6918	13·40	317
24	7053	7·84	314	24	7245	13·65	327
25	7365	9·16	312				

Mean period from the maxima = $315^{d}\cdot8 \pm 1^{d}\cdot3$ (m.e.).
,, ,, minima = $315^{d}\cdot8 \pm 2^{d}\cdot7$ (m.e.).
Limits of maximum brightness $7^{m}\cdot72$ and $10^{m}\cdot00$.
,, minimum brightness $13^{m}\cdot19$ and $14^{m}\cdot05$.
Mean maximum brightness $8^{m}\cdot58$.
,, minimum ,, $13^{m}\cdot51$.
,, amplitude ,, $4^{m}\cdot93$.
Mean value of max. to min. 179^{d} (between 156^{d} and 202^{d}).
,, of min. to max. 137^{d} (,, 120^{d} ,, 154^{d}).

6. The variability of the maximum brightness has already been mentioned by L. Pračka.* His conclusion of a symmetrical light-curve has been premature, as is clear from the curve and the figures given above. Pračka's observations yield 3 maxima on J.D. 241 7903 ($8^{m}\cdot1$), 8217 ($8^{m}\cdot0$) and 8542 ($8^{m}\cdot7$?), but the gap between his last observation (8553) and the first one of the present discussion (9415) is too large to include his results in the latter.

* *Bull. Ac. des Sc. de Bohème*, 1909 ; *Ber. des Astroph. Obs. Nižbor in Böhmen*, Serie I, No. 1.

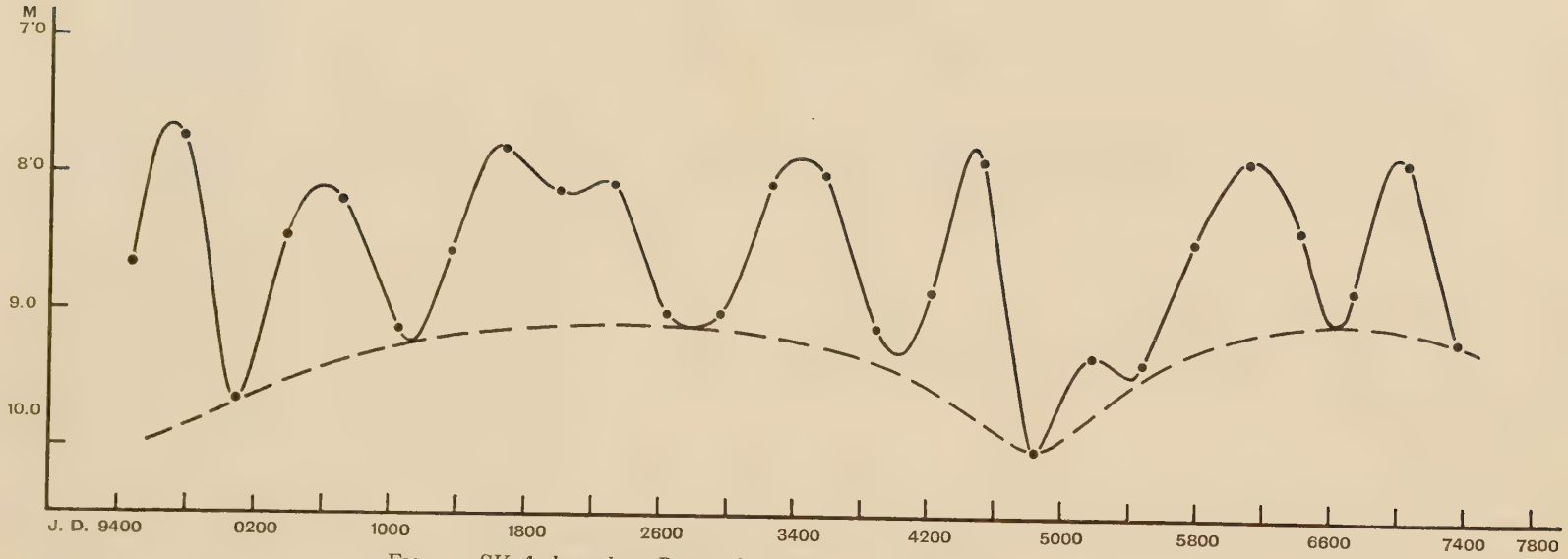


FIG. 1.—*SV Andromedæ*. $P_1 = 316^d$, $P_2 = 930^d$, $P_3 = 5400^d$? $p = 2{\cdot}95$, $q = 5{\cdot}8$.

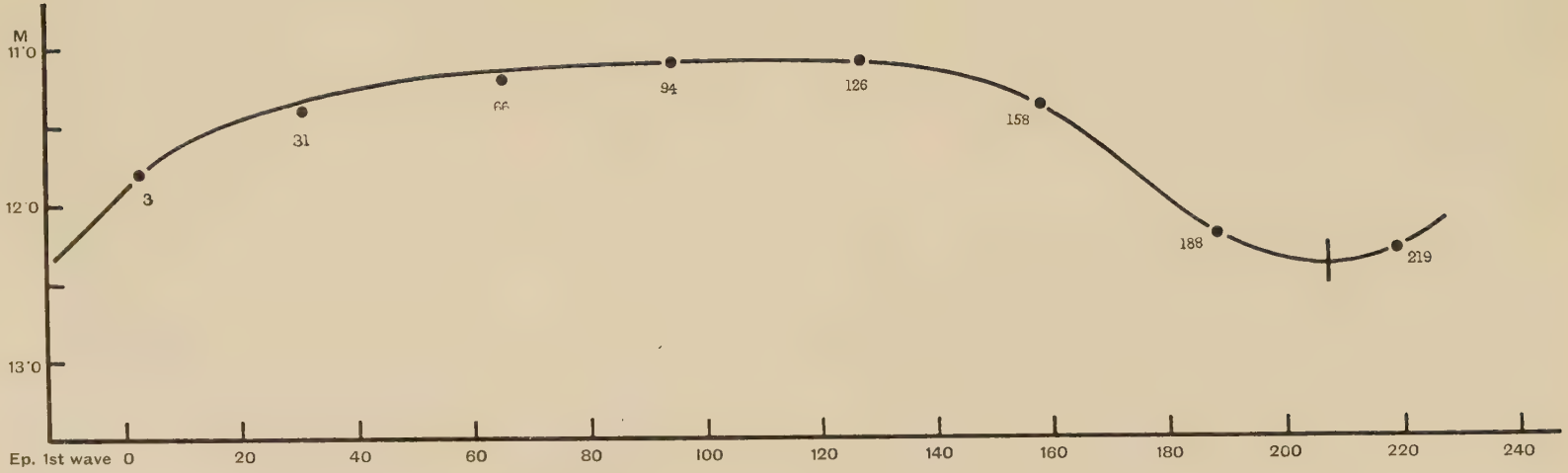


FIG. 2.—*RV Tauri*. $P_1 = 39^d{\cdot}25$, $P_2 = 1220^d$, $P_3 = 8000^d$? $p = 31$, $q = 6{\cdot}6$.

Fig. 1 is a plot of the 25 maxima of Table VI. It clearly shows the maximum brightness to vary in a continuous and systematic way. I have drawn, in a tentative way, a curve through the points, and shall call it the second wave. This wave is irregular, with a mean period of about 930 days.

The minima do not show the same periodicity as the maxima. It cannot be said whether this is real or apparent; for if my suggestion about the magnitudes of the 3 faintest comparison stars is well founded, all the minima on Plate 1 will be too flat, but to various degrees.

7. A glance at fig. 1 shows the remarkable fact that the minima of the second wave are of very different depth. In fact, they seem to exhibit a third periodicity, only two minima of which have occurred in the 22 years covered by the observations. The period of this third wave is roughly 5400 days.

8. It is an interesting fact that the same complex character as derived here for the light-variation of a "long period" variable is exhibited by RV Tau, period about 39 days and assigned to a different class of variables. The second wave of this star has been mentioned in 1908 by Enebo,* in 1916 by the present writer in his monograph on this star,† in 1927 by Nijland ‡ and in 1930 by Beyer,§ who seems to have been unaware of the work of the two Utrecht observers.

Whoever will take the trouble to look at Plate 2 of my monograph will be struck by the fact that there is an indication of a systematically decreasing amplitude of the second wave. This fact was remarked at the time, but considered not to be sufficiently well established. Since 1916 RV Tau has regularly been watched by Nijland. Though his estimates have not yet been carefully discussed, the mean period of the second wave can be derived from them much more accurately than ever before.

Fig. 2 is a plot of all the minima of the second wave, exhibited by the *minima* of RV Tau, as observed and published (see note 3 below) by Nijland. The numbers are the epochs of the minima of the first wave.

The mean value of the period of the second wave is 31 epochs = 31 × 39·25 days = *1220* days.

A glance at fig. 2 again clearly shows the existence of a third periodicity. The period of this third wave is roughly 8000 days.

9. The results obtained here emphasize the importance of observing variable stars continuously, whether this be done by one and the same observer with the same instrument during a lifetime, or by co-operation of the members of associations.

A good chart of the field of SV And can be obtained by mapping cliché No. 1 of the Helsingfors Carte du Ciel (Cat. photogr., tome 1, fasc. 2). The variable is No. 168 of the cliché; for the comparison stars see *J.d.O.*, **15**, No. 9.

* S. Enebo, "Beob. veränd. Sterne, angestellt auf Dombaas (Norwegen)," *Arch. for Math. og naturvid*, Bd. **29**, Nr. 11.

† J. van der Bilt, "An Analysis of the Light-curve of RV Tauri," *Rech. Astr. de l'Obs. d'Utrecht*, 6.

‡ A. A. Nijland, "Beob. von langper. Variablen," *Astr. Nachr.*, Nr. 5491.

§ M. Beyer, "Beob. und Unters. des Lichtwechsels von 48 veränd. Sternen," *Astr. Abh.*, Bd. **8**, Nr. 3.

University Observatory, Utrecht:
1934 *June* 26.

NOTE ON COMPLEX LIGHT-CURVES.

J. van der Bilt, Ph.D.

A number of variable stars are known to show a light-curve composed of a short and a long wave. Sometimes the long periodicity is apparent only from the maxima of the short wave, sometimes only from the minima, sometimes from both phases. If the phenomenon which yields the long periodicity originates in the star itself, both phases will probably be affected ; if it originates outside the star, as in the case of a close variable companion, the maxima would be practically unaffected.

Recently two papers have appeared which emphasize the importance of a closer study of the matter, and the present note may do the same.

(*a*) In Bulletin No. 2 of the Leningrad University Astronomical Observatory (1933 April 15) W. Zessewitsch has published a list of 9 variable stars with a long and a short period, correlated with each other. Plotting their proportion p against the logarithm of the short period P, he was led to infer the existence of an empirical connection, given by the formula

$$p = 80{\cdot}2 - 44{\cdot}5 \log P + 6{\cdot}7 (\log P)^2.$$

He suggested the possibility of discussing the mechanical nature of pulsation by the aid of this formula.

(*b*) In Bulletin 893 of the Harvard College Observatory (1933 Oct. 1), D. J. K. O'Connell, S.J., from the two periods of again 9 stars, arrived at a quadratic relation between the two. Plotting the two periods against each other he found the stars to lie close to a smooth curve which might be a hyperbola.

The two publications have 6 of the 9 stars in common. One of these is UZ Persei, the periods in Zessewitsch's paper are $90{\cdot}7^d$ and 5000^d, and in O'Connell's 90^d and 920^d. The three additional stars in Zessewitsch's paper are (i) RV Tauri, whose short period is given as $78{\cdot}6^d$, which, in my opinion, ought to be $39{\cdot}25^d$ (see *Rech. Astr. de l'Obs. d'Utrecht*, 6) ; (ii) UU Aurigæ and (iii) μ Cephei. Instead of these 3 additional stars O'Connell's paper has DF Cygni, TW Pegasi and W Orionis.

There are two misprints in Zessewitsch's paper. On p. 2, last line, read *Astr. Abh.*, 8, instead of 4, and on p. 3, second line, read *P.A.*, 34, 551, instead of 151.

In view of the importance of the problem and the wide field of investigation opened by the detection of a complex light-variation of the same kind in two stars till now assumed to be of different classes (see the foregoing paper on SV And), I may be justified in publishing again a list of stars whose light-curves are built up by waves of different periods. The table below gives, for 14 stars, P_1 = shortest period, P_2 = long period and P_3 =

still longer period. The ratios $P_2 : P_1$ and $P_3 : P_2$ have been called p and q respectively.

TABLE I

Stars with Complex Light-curves

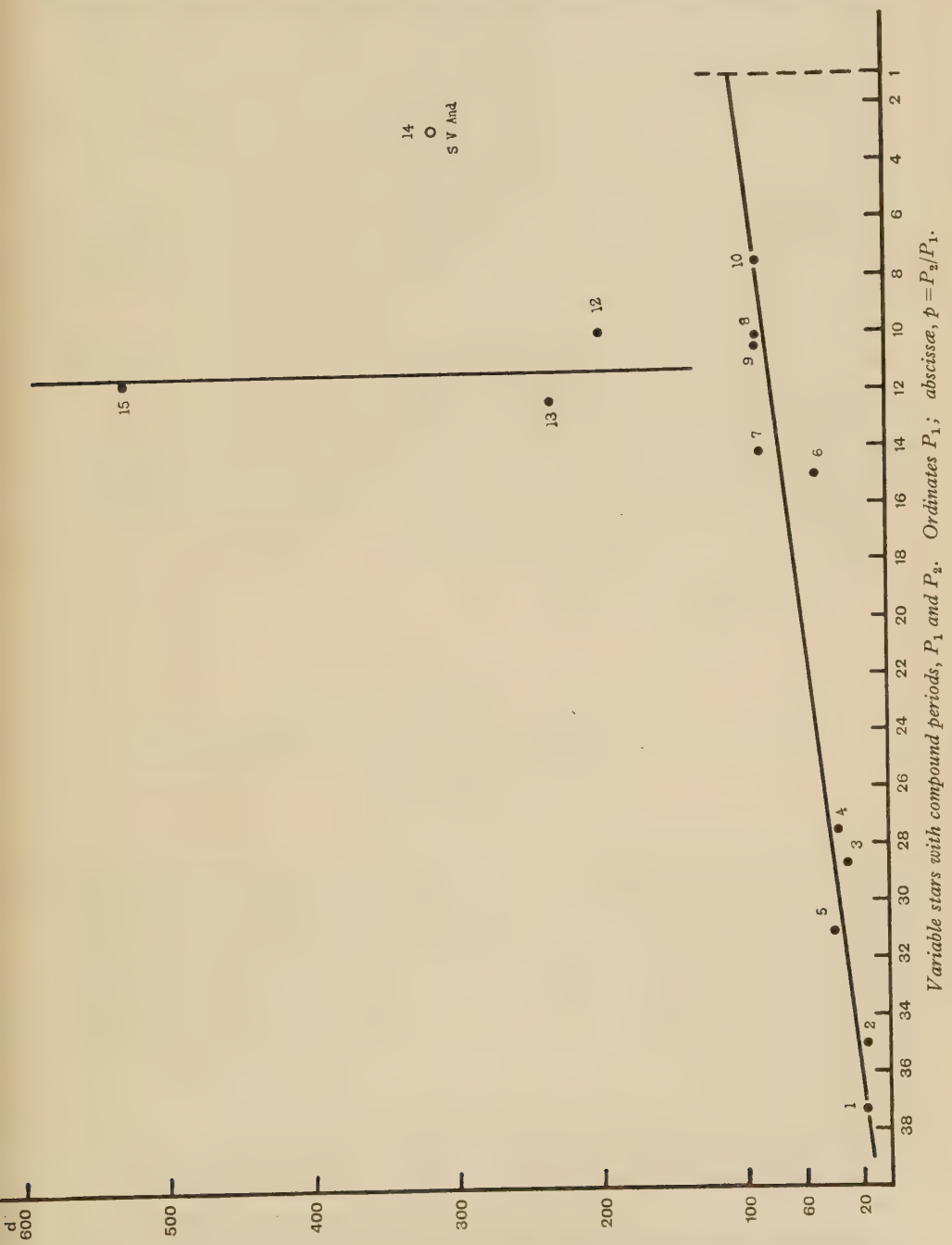
	Star	Sp.	P_1	P_2	P_3	p	q	Notes
			d	d				
1	SX Cent	F5	16·5	615		37·4		
2	V Sag		17·2	600		35·0		1
3	SU Gem	K6	24·9	716		28·8		
4	AI Scorp	K	35·6	1000		28·1		2
5	RV Tau	Ko	39·2	1220	8000	31·1	6·6	
6	DF Cyg	K2	49·9	750		15·0		
7	AF Cyg	M4	88·6	1259		14·2		
8	UZ Pers	M4	90	915	5000	10·1	5·5	
9	TW Peg	M6	90	1000		11·1		3
10	μ Ceph		90 ?	750	4675	8·3	6·2	4
11	VY And		149					5
12	W Or	Nb	200	2000		10·0		
13	UU Aur	Na	235	2920		12·4		
14	SV And	M7e	316	930	5400	2·94	5·8	
15	V Hydr	N	532	6350		11·8		

Notes : 1. Prager's *Katalog* (1934) has $P_2 > 600^d$.
2. Prager : 980^d ; Voûte : $\pm 1025^d$.
3. P_2 from latest publication by Lause, *Astr. Nachr.*, No. 6028.
4. P_1 from *Gesch. u. Lit. der veränd. Sterne*, 2, 339 ; P_2 from Zessewitsch's paper.
5. Prager only reports the existence of long per. fluct. of the mean magn., but no length of period.

I have plotted p against P_1 in the accompanying diagram ; it shows clearly the systematic relation to which Zessewitsch and O'Connell have drawn attention. However, before making further references as to the nature of the connection, it must be remembered that it is not difficult to detect a second period of 40 to 10 times and even to 5 times the first, but that this becomes increasingly difficult for smaller values of p. The amplitudes and the phases of the two waves then begin to play an important rôle, and at values of p between 2 and 1 such waves can only be disentangled by the tedious and dangerous process of periodogram-analysis. For this I may refer the reader to *Rech. Astr. de l'Obs. d'Utrecht*, 6, 94, and to *B.A.N.*, 4, 149. This means that, from the absence of points with p between 5 and 1 for P_1 between, say, 90 and 110 days (see diagram), it does not follow that such stars do not exist. If both waves are to a certain extent irregular in amplitude and phase (which is generally the case), the true character of the complex light-variation may remain hidden when the amplitudes are small and of the same order of magnitude.

It therefore remains an open question whether the tracing of curves like those of Zessewitsch and O'Connell is justified. In our diagram it

rather looks as if the stars 1 to 10 are members of a group with a *linear* connection between the periods of the two waves; these become equal



Variable stars with compound periods, P_1 and P_2. Ordinates P_1; abscissæ, $p = P_2/P_1$.

($p = 1{\cdot}0$) at P_1 between 100 and 110 days. RR Lyræ is not a member of this group, since for $P_1 = 0{\cdot}6$ p would be 45 instead of 72.

Of the remaining 4 stars, SV And is far outside the relation shown by the others. These three, all N stars, seem to constitute a group for which p is practically constant (mean value = 11·4) between P_1 200 and 532 days.

VY And with $P_1 = 149^d$ is between the two groups, and a detailed study of its light-variation seems very desirable.

These statements have not been made in support of any theory; I have only made them partly as a warning against premature conclusions and partly to urge the necessity of further researches.

Table I has only 4 stars with three waves. This number is too small for definitive conclusions as to q. Considering, however, that for RV Tau and SV And P_3 has been derived from good, homogeneous material, and that also for μ Cephei both P_2 and P_3 seem to be well established, I think it worth while to draw attention to the fact *that q seems to have a constant value* which in a preliminary way may be fixed at *6*. This result, as well as the constant value of p for the larger values of P_1 ($p = 2q$?), may have some meaning with respect to the theory of stellar pulsations.

I should like to conclude this note with the remark that reliable curves obtained from homogeneous material, running over a long interval of time, may clear up many points with regard to the complexity of stellar variation. Undoubtedly such material is already present in the manuscripts of a few single observers and in great wealth in the volumes of the *B.A.A.*, only waiting to be properly handled.

University Observatory, Utrecht :
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ON A SPECIAL CASE IN THE DETERMINATION OF PROBABLE ERRORS.

J. C. P. Miller, Ph.D.

§ 1. In determining lunar diurnal variations in geophysical elements (such as barometric pressure or the magnetic field) it is convenient first to obtain the solar diurnal harmonic components of the variation from groups of days, each corresponding to a particular age of the moon. The resulting values of the amplitude and phase of any component may be represented by vectors, there being one such vector for each group of days. These components include a solar part which we take to be the same in amplitude and phase in all the groups ; this is determined from the mean of the results for all groups.

When this constituent is removed, the results include a true lunar variation together with a part of accidental origin. The lunar part is supposed to be of the same constant amplitude in each group, while its phase varies regularly from group to group in a way which is known from theory.

When the amplitude and phase of the lunar part have been found, there remains the problem of determining the magnitude of the accidental part of the component variation, for it is from this that we must infer the probable

error of the lunar diurnal variation itself. The problem can be expressed in simple mathematical form as follows :—

§ 2. Consider a plane set of points $P_m (m = 1 \text{ to } m = n)$ which specify a set of vectors $\mathbf{R}_m$ represented by the lines OP_m drawn from an origin O.

These vectors are supposed made up of two parts

$$\mathbf{R}_m = \mathbf{L}_m + \mathbf{A}_m,$$

where $\mathbf{L}_m$ is a vector OL_m corresponding to the lunar diurnal variation, of constant amplitude L and of phase l_m which is known but not constant, while $\mathbf{A}_m$ is a vector $L_m P_m$, of amplitude A_m and phase $l_m + \theta_m$, where θ_m is uncorrelated with l_m. Let $\mathbf{R}'_m$ and $\mathbf{A}'_m$ denote vectors equal to $\mathbf{R}_m$ and $\mathbf{A}_m$ except that their phases are reduced by the amount l_m. Then

$$R_m = R'_m, \qquad A_m = A'_m$$

and

$$\mathbf{R}'_m = \mathbf{L} + \mathbf{A}'_m,$$

where $\mathbf{L}$ is now a constant vector of length L and zero phase. It is supposed that the vectors $\mathbf{A}'_m$ have a Gaussian distribution, so that the number whose amplitudes lie between r and $r + dr$, and whose phases lie between θ and $\theta + d\theta$, is given by

$$\frac{h^2}{\pi} n e^{-h^2 r^2} r \, d\theta \, dr.$$

Then the mean value (A) of A_m is given by

$$A = \frac{h^2}{\pi} \int_0^\infty \int_0^{2\pi} e^{-h^2 r^2} r^2 \, d\theta \, dr = \frac{\sqrt{\pi}}{2h} = \cdot 8862/h,$$

and the probable error r_0 of any one of the vectors OP_m is given by

$$1 - e^{-h^2 r_0^2} = \tfrac{1}{2} \quad \text{or} \quad r_0 = \cdot 8326/h,$$

so that

$$r_0 = \cdot 9394 A.$$

§ 3. It is desired to determine A from the mean (R) of the amplitudes R_m, these being much more readily evaluated than A_m. The relation between A and R must clearly involve L, and in the first instance R is obtained as a function of A and L. This functional relation must be inverted in order to obtain A as a function of L and R. The relation found is of the form

$$\frac{r_0}{R} = \frac{\cdot 9394 A}{R} = f\left(\frac{L}{R}\right).$$

The function $f(L/R)$ is tabulated in Table I ; it varies rapidly (tending to zero) when L/R is nearly unity, and in this case A cannot in practice be found with sufficient accuracy from this relation.

If the phases l_m are known it is, of course, possible to measure the individual distances A_m and to obtain their mean directly. In the actual applications to lunar diurnal periodicities the work can be slightly simplified

when $L/R \doteqdot 1$, because of the fact that the successive phases $l_m (m = 1 \text{ to } 12)$ in those applications differ by amounts which are nearly equal to 30°. This case is briefly considered in § 6, and a function f' (corresponding to f) is tabulated in Table II.

In order to facilitate the evaluation of individual A_m's in cases where this is desired, we give $\sin l_m$, $\cos l_m$ in Table III, taking $l_0 = \pi$.

§ 4. Clearly

$$R_m^2 = L^2 + A_m^2 + 2LA_m \cos \theta_m,$$

and consequently

$$R = \frac{h^2}{\pi} \int_0^\infty \int_0^{2\pi} e^{-h^2 r^2} (L^2 + r^2 + 2Lr \cos \theta)^{1/2} r d\theta dr,$$

or putting $r = L\rho$, $h = \lambda/L$, $R = AS$

$$S = \frac{2\lambda^3}{\pi^{3/2}} \int_0^\infty \int_0^{2\pi} e^{-\lambda^2 \rho^2} \rho (1 + 2\rho \cos \theta + \rho^2)^{1/2} d\theta d\rho.$$

As $\lambda \equiv \frac{\sqrt{\pi}}{2} \cdot \frac{L}{A} \to 0$, $\quad R \to A$ and $S \to 1$.

As $\lambda \to \infty$, $\quad R \to L$ and $S \to 2\lambda/\sqrt{\pi}$.

Dr. R. J. Schmidt and I have succeeded in showing that

$$\lambda \frac{d^2 S}{d\lambda^2} + (2\lambda^2 + 1) \frac{dS}{d\lambda} - 2\lambda S = 0.$$

To see this, note that

$$\int_0^{2\pi} \frac{(1 + \rho \cos \theta)(\rho + \cos \theta)}{(1 + 2\rho \cos \theta + \rho^2)^{3/2}} d\theta = \int_0^{2\pi} \frac{\cos \theta (1 + 2\rho \cos \theta + \rho^2) + \rho \sin^2 \theta}{(1 + 2\rho \cos \theta + \rho^2)^{3/2}} = 0, \quad (4{\cdot}1)$$

integrating the second term on the right by parts.

Put

$$u = \int_0^{2\pi} (1 + 2\rho \cos \theta + \rho^2)^{1/2} d\theta$$

$$= \int_0^{2\pi} \frac{(1 + 2\rho \cos \theta + \rho^2)^2}{(1 + 2\rho \cos \theta + \rho^2)^{3/2}} d\theta = \int_0^{2\pi} \frac{(\rho^2 - 1)^2}{(1 + 2\rho \cos \theta + \rho^2)^{3/2}} d\theta.$$

Then

$$\frac{du}{d\theta} = \int_0^{2\pi} \frac{(\rho + \cos \theta) d\theta}{(1 + 2\rho \cos \theta + \rho^2)^{1/2}} = \int_0^{2\pi} \frac{(\rho^2 - 1)(\rho + \cos \theta)}{(1 + 2\rho \cos \theta + \rho^2)^{3/2}} d\theta,$$

$$\frac{d^2 u}{d\theta^2} = \int_0^{2\pi} \frac{d\theta}{(1 + 2\rho \cos \theta + \rho^2)^{1/2}} - \int_0^{2\pi} \frac{(\rho + \cos \theta)^2}{(1 + 2\rho \cos \theta + \rho^2)^{3/2}} d\theta$$

$$= \int_0^{2\pi} \frac{\left(2 + \frac{\rho^2 + 1}{\rho} \cos \theta\right)}{(1 + 2\rho \cos \theta + \rho^2)^{3/2}} d\theta,$$

using (4·1) to eliminate $\cos^2 \theta$ from the numerator in each case.

Combining the above relations, we have

$$(\rho^3-\rho)\frac{d^2u}{d\theta^2}-(\rho^2+1)\frac{du}{d\theta}+\rho u=0. \tag{4·2}$$

Now

$$\lambda^s\int_0^\infty \rho^n f(\rho)e^{-\lambda^2\rho^2}d\rho=\left[-\frac{\lambda^{s-2}\rho^{n-1}}{2}f(\rho)e^{-\lambda^2\rho^2}\right]_0^\infty+\tfrac{1}{2}\lambda^{s-2}\int_0^\infty\frac{d\{f(\rho)\rho^{n-1}\}}{d\rho}e^{-\lambda^2\rho^2}d\rho,$$

so that

$$\left.\begin{aligned}
S&=\frac{2\lambda^3}{\pi^{3/2}}\int_0^\infty \rho u e^{-\lambda^2\rho^2}d\rho=\frac{\lambda}{\pi^{3/2}}\left(1+\int_0^\infty\frac{du}{d\rho}e^{-\lambda^2\rho^2}d\rho\right)\\
\frac{dS}{d\lambda}&=\frac{6\lambda^2}{\pi^{3/2}}\int_0^\infty \rho u e^{-\lambda^2\rho^2}d\rho-\frac{4\lambda^4}{\pi^{3/2}}\int_0^\infty \rho^3 u e^{-\lambda^2\rho^2}d\rho\\
&=\frac{2\lambda^2}{\pi^{3/2}}\int_0^\infty\left(\rho u-\rho^2\frac{du}{d\rho}\right)e^{-\lambda^2\rho^2}d\rho\\
&=\frac{1}{\pi^{3/2}}\left(1-\int_0^\infty\rho\frac{d^2u}{d\rho^2}e^{-\lambda^2\rho^2}d\rho\right)\\
\frac{d^2S}{d\lambda^2}&=\frac{2\lambda}{\pi^{3/2}}\int_0^\infty\rho^3\frac{d^2u}{d\rho^2}e^{-\lambda^2\rho^2}d\rho.
\end{aligned}\right\} \tag{4·3}$$

From (4·2) and (4·3) we find, as required,

$$\left.\begin{aligned}
&\lambda\frac{d^2S}{d\lambda^2}+(2\lambda^2+1)\frac{dS}{d\lambda}-2\lambda S=0\\
&\text{with the boundary conditions}\\
&\qquad S=1 \text{ when } \lambda=0,\\
&\frac{dS}{d\lambda}\to 2/\sqrt{\pi} \text{ as } \lambda\to\infty.
\end{aligned}\right\} \tag{4·4}$$

§ 5. From (4·4) we find

$$S=1+\tfrac{1}{2}\lambda^2-\tfrac{1}{16}\lambda^4+\tfrac{1}{96}\lambda^6-\ \ldots\ +(-)^{r-1}\frac{1\cdot 3\cdot 5\cdot\ldots\cdot(2r-3)}{2^r\cdot(r!)^2}\lambda^{2r}+\cdots \tag{5·1}$$

which is convergent for all λ, but not convenient for large λ, for which case we have the asymptotic expansion

$$S=\frac{2\lambda}{\sqrt{\pi}}\left(1+\frac{1}{4\lambda^2}+\frac{1^2}{2!\,(2\lambda)^4}+\frac{1^2\cdot 3^2}{3!\,(2\lambda)^6}+\ \ldots\right). \tag{5·2}$$

These expressions are both of the form

$$\frac{R}{L}\cdot\frac{L}{A}=\phi\left(\frac{L}{A}\right).$$

L and R are supposed known and we wish to find A, so (5·1) and (5·2) must be converted to the form $\dfrac{L}{A}=F\left(\dfrac{L}{R}\right)$,

$$\frac{r_0}{R}=\frac{\cdot 9394A}{R}=\cdot 9394\frac{L}{R}\Big/\frac{L}{A}=f(L/R)$$

can then readily be found.

From (5·1) and (5·2) we find

$$\lambda = \frac{\sqrt{\pi}}{2} \cdot \frac{L}{A} = \nu + \tfrac{1}{2}\nu^3 + \tfrac{7}{16}\nu^5 + \tfrac{43}{96}\nu^7 + \tfrac{505}{1024}\nu^9 + \cdots \qquad (5\cdot3)$$

and

$$\frac{1}{4\lambda^2} = \frac{A^2}{\pi L^2} = \sigma - \tfrac{1}{2}\sigma^2 - \sigma^3 - \tfrac{25}{4}\sigma^4 - \tfrac{501}{4}\sigma^5 - \cdots \qquad (5\cdot4)$$

where $\nu = \dfrac{\sqrt{\pi}}{2} \cdot \dfrac{L}{R}$, $\qquad \sigma = \dfrac{R}{L} - 1$.

To fill the gap between (5·3) and (5·4) we use (5·1) and interpolate. The function $f(L/R)$ is tabulated in Table I.

§ 6. In § 3 we noted that for $\dfrac{L}{R} \doteqdot 1$, Table I does not give a sufficiently accurate value for A.

When we are dealing with lunar periodicities, the phases l_m are as follows, apart from a possible constant added to each:—

m	l_m	$l''_m = l_m - 30°\,(m-7)$
	°	°
1	180	0
2	144·9	−5·1
3	115·9	−4·1
4	87·0	−3·0
5	58·0	−2·0
6	29·0	−1·0
7	0	0
8	− 29·0	1·0
9	− 58·0	2·0
10	− 87·0	3·0
11	−115·9	4·1
12	−144·9	5·1

Phase changes which are multiples of 30° are very simple to apply numerically. In the third column we give the residuals after the phase of $\mathbf{L}_m + \mathbf{A}_m$ has been reduced by 30° $(m-7)$.

Let $\mathbf{L}''_m + \mathbf{A}''_m$ denote the vector $\mathbf{L}_m + \mathbf{A}_m$ after this phase change has been made. $\mathbf{L}''_m$ has amplitude L and phase l''_m and $\mathbf{A}''_m$ has amplitude A_m and phase $\theta_m + l''_m$. The mean $\mathbf{L}''$ of the vectors L''_m has amplitude

$$L'' = \tfrac{1}{12}\Sigma L \cos l''_m = \cdot 99856L$$

and phase

$$l'' = \tfrac{1}{2}\Sigma l''_m = 0.$$

We wish to express A in terms of the mean R' of distances measured from the end point of the mean vector $\mathbf{L}''$.

Denote by L'_m the amplitude of the vector $\mathbf{L}_m - \mathbf{L}''_m$. We then have

$$L_1' = L_7' = \cdot 00144L$$
$$L_2' = L_{12}' = \cdot 08858L$$
$$L_3' = L_{11}' = \cdot 07088L$$
$$L_4' = L_{10}' = \cdot 05317L$$
$$L_5' = L_9' = \cdot 03547L$$
$$L_6' = L_8' = \cdot 01778L.$$

For each L_m' we have a series

$$S_m' = 1 + \tfrac{1}{2}k_m^2\lambda^2 - \tfrac{1}{16}k_m^4\lambda^4 + \tfrac{1}{96}k_m^6\lambda^6 - \cdots$$

where $k_m = L_m'/L$.

Whence

$$\frac{R'}{A} = S' = \tfrac{1}{12}\sum_1^{12} S_m' = 1 + \left(\tfrac{1}{12}\sum_1^{12} k_m^2\right)\tfrac{1}{2}\lambda^2 - \left(\tfrac{1}{12}\sum_1^{12} k_m^4\right)\tfrac{1}{16}\lambda^4 + \cdots$$

$$= 1 + 0\cdot 0^2 1439\lambda^2 - 0\cdot 0^5 1005\lambda^4 + 0\cdot 0^8 1102\lambda^6 - 0\cdot 0^{11} 1219\lambda^8 + 0\cdot 0^{14} 126\lambda^{10}.$$

Converting to express L/A in terms of L/R' as before, we have

$$\lambda = \frac{\sqrt{\pi}}{2}\frac{L}{A} = \cdot 8862\frac{L}{R'} + 0\cdot 0^2 1002\left(\frac{L}{R'}\right)^3 - 0\cdot 0^5 1716\left(\frac{L}{R'}\right)^5 + 0\cdot 0^8 3149\left(\frac{L}{R'}\right)^7 - 0\cdot 0^{11} 584\left(\frac{L}{R'}\right)^9 + \cdots$$

From this we derive $f'(L/R')$, given in Table II, such that

$$\frac{r_0'}{R'} = f'(L/R').$$

r_0' will, of course, be equal to r_0 when both are reliable.

§ 7. Comparison of Probable Errors given by

$$r_0 = Rf(L/R) \quad \text{and} \quad r_0' = R'f'(L/R').$$

In forty cases, in which L/R lies between ·45 and ·93, probable errors were obtained by using both relations. We suppose in each case that r_0' is the value to be preferred, and express $|r_0 - r_0'|$ as a percentage of r_0'. We can then infer a maximum disagreement, which is a function of L/R.

L/R	·6	·75	·8	·9
$\text{Max}\left\lvert\frac{r_0 - r_0'}{r_0'}\right\rvert$	8%	15%	20%	40%

It is evident that r_0 is not safe if L/R exceeds about ·75. Comparison of Table I and Table II suggests that r_0' should be reliable for $L/R' < 15$, and so anywhere within the limits of Table II.

Table I

L/R	$f(L/R)$	L/R	$f(L/R)$
0·0	·9394	0·5	·8392
0·05	·9385	0·55	·8157
0·1	·9357	0·6	·7887
0·15	·9311	0·65	·7575
0·2	·9245	0·7	·7213
0·25	·9159	0·75	·6789
0·3	·9053	0·8	·6280
0·35	·8925	0·85	·5650
0·4	·8773	0·9	·4819
0·45	·8597	0·95	·3573
0·5	·8392	1·0	0

Table II

L/R'	$f'(L/R')$	L/R'	$f'(L/R')$
0	·9394	6	·9004
1	·9384	7	·8858
2	·9352	8	·8688
3	·9298	9	·8490
4	·9223	10	·8264
5	·9125	11	·8007
6	·9004	12	·7714

Table III

r	s	$l_r = -l_s$	$\sin l_r$	$\cos l_r$
		°		
1		180	0	−1
2	12	144·9	·57472	− ·81835
3	11	115·9	·89929	− ·43735
4	10	87·0	·99858	·05318
5	9	58·0	·84776	·53039
6	8	29·0	·48457	·87475
7		0	0	1

I wish to express my thanks to Professor S. Chapman for the interest he has taken in this work.

THE IRON ARC SPECTRUM FROM λ 8838 TO λ 10219 A.

Herbert Dingle, D.Sc.

Introduction.—The recent production on a commercial scale of photographic plates sensitive to infra-red radiations has made possible a considerable extension of many branches of spectroscopy. In order to take advantage of this possibility, however, standards of wave-length in the new region are required. The latest report of the Wave-Lengths Commission of the International Astronomical Union * contains accurate measures by Babcock of a number of lines occurring in the solar spectrum, but such lines are

* *Trans. I.A.U.*, 4, 58, 1932.

insufficient for general use because of the impossibility in many laboratories of admitting sunlight *ad lib.* to the spectrographs. The iron arc, which provides most of the standards for the ordinary regions, has many infra-red lines up to λ 10200, and it would seem to be a natural source of standards for this region on account of its simplicity in use and the fact that the conditions of its running for consistent results have already been established.

Interferometer measures of iron lines up to λ 8824 have been made by Meggers and Kiess,* and a map extending to this limit is obtainable from Messrs. Adam Hilger. For higher wave-lengths, however, no satisfactory measures and no photographs appear to have been published. In some recent work with a prismatic spectrograph on the fluorine spectrum in the infra-red, in which an iron comparison spectrum was used, the author attempted to identify the reference lines from the table collected by Catalán.† The lines recorded, however, were insufficient in number, the accuracy of the wave-lengths appeared doubtful, and it was impossible with any confidence to associate the lines photographed with those tabulated owing to ignorance of the law of dispersion of the spectrograph in this region and the absence of a map. It was necessary, therefore, to make an independent investigation of the iron spectrum, the results of which are given in this paper for general use.

Experimental Arrangements.—The spectrum of the iron arc in air at 110 V. was photographed in the 1st order of the 10-foot Rowland concave grating (Eagle mounting) at the Imperial College, the 2nd (and, for the lines of greatest wave-length, the 3rd) order spectrum of the same source serving as an adjacent comparison. The wave-lengths of the latter which were adopted as standards were those of the 1928 Report of the I.A.U. Wave-Lengths Commission.‡ Exposures of from 5 to 6 hours were necessary for the 1st order, and from 1 to 2 minutes for the 2nd. The 1st order lines were photographed through an Ilford infra-red filter placed before the slit. This entirely eliminated lines of higher orders, while the comparative shortness of the subsequent exposure to the 2nd order, in which no filter was used, kept the reference spectrum free from 1st order lines. The dispersion in the 1st order was 5·3 A. per mm. The plates used were Eastman I/Q, hypersensitised in an ammonia bath immediately before exposure. The slit was made fairly wide in order to keep the exposures within a reasonable duration.

Results.—The results of the measurements are given in the table, and the infra-red spectrum is reproduced in Plate 8. The recorded intensities are merely eye estimates of the blackening of the plate, on a scale with 1 for the weakest and 10 for the strongest lines. They have much less than the usual significance of such estimates on account of the rapidly varying sensitivity of the plates with wave-length. For practical purposes, however, this is immaterial so long as the same type of plate is used.

It should be clearly understood that the wave-lengths given are not

* *Sci. Pap. Bur. Stand., Washington,* No. 479, 1924.
† *Anales de la Soc. Esp. de Fis. y Quim.*, **28**, 1239, 1930.
‡ *Trans. I.A.U.*, **3**, 86, 1928.

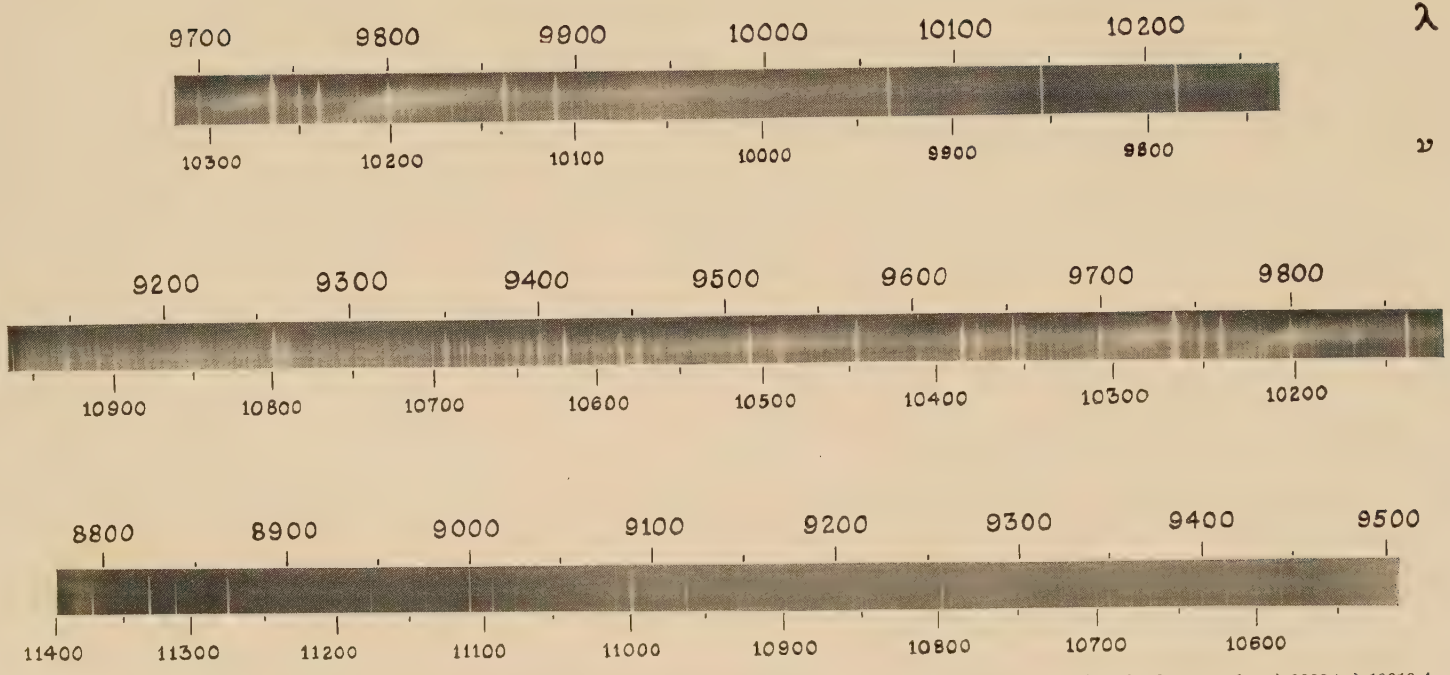
Table of Wave-Lengths and Wave-Numbers

λ (Int.)	Wave-number ν	No. of Plates Measured	λ (Int.)	Wave-number ν	No. of Plates Measured
10218·41 (1)	9783·58	1	9350·50 (4)	10691·69	3
216·44 (5)	85·46	1	43·49 (2)	699·70	2
145·69 (4)	9853·70	1	18·25 (1)	728·69	1
065·08 (6)	9932·62	3	9259·04 (3)	797·29	3
9889·10 (8)	10109·37	3	58·38 (5)	798·07	3
68·13 (2)	130·86	1	46·66 (1)	811·75	1
61·85 (7)	137·31	3	17·59 (2)	845·85	2
00·38 (6)	200·90	3	14·52 (3)	849·46	3
9786·52 (2)	215·34	1	12·45 (1)	851·89	1
83·97 (2)	218·00	2	10·05 (3)	854·74	3
63·63*(6)	239·29	3	9173·80 (1)	897·62	1
53·17 (5)	250·27	3	64·65 (1)	908·51	1
47·11 (1)	256·64	1	48·08 (2)	928·26	1
38·64 (10)	265·56	3	46·19 (2)	930·51	2
9699·70 (4)	306·77	3	18·92 (6)	963·21	2
57·32 (3)	352·00	2	00·50 (2)	985·39	1
53·20 (5)	356·43	3	9089·43 (5)	998·78	2
37·59 (2)	373·20	2	88·35 (7)	11000·08	2
36·69 (1)	374·17	1	80·44 (1)	009·66	1
34·26 (3)	376·78	3	79·68 (3)	010·59	2
26·60 (6)	385·04	3	24·49 (2)	077·93	2
9570·02 (7)	446·44	2	12·17 (4)	093·07	2
29·27 (2)	491·11	1	10·64 (1)	094·95	2
13·26 (4)	508·76	3	8999·56 (8)	108·60	2
9462·97 (1)	564·61	2	84·94 (2)	126·69	1
54·35 (2)	574·25	2	75·43 (2)	138·47	2
52·56 (2)	576·24	2	45·21 (3)	176·11	2
43·98 (4)	585·85	3	43·13 (1)	178·70	2
30·11 (2)	601·43	3	29·21 (1)	196·13	1
14·13 (7)	619·42	3	20·10 (2)	207·56	1
01·18 (5)	634·04	3	8868·44 (2)	272·85	2
9372·92 (4)	666·11	3	67·00 (7)	274·68	2
62·40 (3)	678·09	3	46·95 (2)	300·23	2
59·40 (2)	681·51	2	38·46 (4)	311·09	2

* ? Double.

proposed as final standards. There are several reasons for this: (1) No investigation of line structure or freedom from pole effect has been made. (2) Although a steady arc was maintained, it cannot be guaranteed, in view of the long exposures and the fact that the infra-red filter made the image on the slit invisible, that the standard conditions were observed throughout. (3) No special precautions were taken to keep the temperature of the spectrograph constant. (4) Insufficient plates were measured. (5) The slit width was too great for the highest accuracy in setting the cross-wires on the lines.

INFRA-RED SPECTRUM OF IRON ARC



H. Dingle, The Iron Arc Spectrum from λ 8838 to λ 10219 A.

(6) The method of overlapping orders is unsatisfactory for ultimate standards. These things apart, however, the usual care was taken, and the result should in no instance be more than a few hundredths of an angstrom in error, the best lines probably being accurate to within 0·01 or 0·02 A.

This degree of accuracy, it might be observed, is for most purposes effectively much higher than that corresponding to errors of the same absolute magnitude in the ordinary regions of observation. In all work in which wave-numbers are significant, for instance (such as the term analysis of spectra), this follows from the fact that a given error in wave-length in the infra-red produces a relatively small error in wave-number; thus, at λ 10,000 the wave-number error is less than one-sixth of that at λ 4000. In measurements of displacements due to radial velocity and Einstein effect, which are proportional to wave-length, an error at λ 10,000 has, on the final result, only two-fifths of the effect of the same error at λ 4000. Furthermore, owing to the comparatively long exposures at present necessary, most work in the less refrangible region must be carried out with instruments of small dispersion, and the uncertainties in the resulting measurements thus inevitably introduced make extreme refinement of standards superfluous. For these reasons it is hoped that the wave-lengths recorded here may have a wide field of usefulness.

It should be added that, in accordance with the essentially practical purpose of the investigation, no attempt was made to obtain pure iron or to eliminate impurity lines from the results. The poles were of ordinary commercial iron, such as might be used in any laboratory. It might be remarked, however, that the 2nd order spectrum showed strong manganese lines and that, though no systematic search was made, no evidence of other impurities was obtained.

Imperial College,
South Kensington:
1934 *July*.

MEAN AREAS AND HELIOGRAPHIC LATITUDES OF SUNSPOTS IN THE YEAR 1933.

(Communicated by the Astronomer Royal)

The results given here are in continuation of those in *M.N.*, **93**, 792, 1933, and are derived from the measurement of photographs taken at the Royal Observatories of Greenwich and the Cape, and at the Kodaikanal Observatory, India.

Table I gives the mean daily areas of umbræ, whole spots and faculæ for each synodic rotation of the Sun included in the year 1933, and the mean values for each year as a whole from 1923 to 1933 are given in Table II.

TABLE I

No. of Rotation	Rotation Commenced G.C.T.	No. of Days on which Sun was photographed	Mean Daily Areas: Projected * Umbræ	Projected * Whole Spots	Projected * Faculæ	Corrected for Foreshortening † Umbræ	Corrected for Foreshortening † Whole Spots	Corrected for Foreshortening † Faculæ
1061	Jan. 6·74	27	69	328	530	54	263	611
1062	Feb. 3·08	27	143	774	531	101	537	651
1063	Mar. 2·42	28	46	218	463	36	162	539
1064	29·73	27	8	36	293	6	28	346
1065	Apr. 26·00	27	4	19	221	3	14	262
1066	May 23·23	28	14	60	229	8	35	276
1067	June 19·43	27	4	21	147	5	25	174
1068	July 16·63	27	0	1	87	0	0	101
1069	Aug. 12·85	27	5	16	57	3	10	66
1070	Sept. 9·09	27	4	18	73	3	11	88
1071	Oct. 6·37	28	16	71	52	10	46	64
1072	Nov. 2·66	27	0	0	89	0	0	102
1073	29·97	27	0	2	41	0	1	43

* Expressed in millionths of the Sun's disc.
† Expressed in millionths of the Sun's hemisphere.

TABLE II

Year	No. of Days: Photographed	No. of Days: Without Spots	Mean Daily Areas: Projected * Umbræ	Projected * Whole Spots	Projected * Faculæ	Corrected for Foreshortening † Umbræ	Corrected for Foreshortening † Whole Spots	Corrected for Foreshortening † Faculæ
1923	365	171	15	74	189	10	55	222
1924	366	97	62	361	498	46	276	575
1925	365	19	189	1102	1508	141	830	1750
1926	365	2	284	1651	2159	217	1262	2556
1927	365	0	248	1417	1812	186	1058	2212
1928	366	0	333	1884	2134	244	1390	2589
1929	365	0	334	1695	2190	245	1242	2567
1930	365	4	145	705	1378	106	516	1630
1931	365	42	79	372	679	57	275	801
1932	366	92	46	216	335	35	163	400
1933	365	234	24	120	225	18	88	267

* Expressed in millionths of the Sun's disc.
† Expressed in millionths of the Sun's hemisphere.

Table III gives for each rotation in the year 1933 the mean daily area of the whole spots (corrected for foreshortening) and the mean heliographic latitude of the spotted areas for both northern and southern hemispheres. The mean heliographic latitude of the entire spotted area and the mean distance from the equator of all spots are also tabulated. The mean values

for the years 1923 to 1933 are given in Table IV. Tables II and IV are in continuation of similar tables given in *Monthly Notices*: for the years 1874 to 1888—**49**, 381–382; 1889 to 1902—**63**, 465–466; 1901 to 1914—**76**, 402–403; 1913 to 1924—**85**, 1007–1008.

TABLE III

No. of Rotation	Rotation Commenced G.C.T.	Spots North of the Equator		Spots South of the Equator		Mean Latitude of entire Spotted Area	Mean Distance from Equator of all Spots
		Mean Daily Area	Mean Heliographic Latitude	Mean Daily Area	Mean Heliographic Latitude		
			°		°	°	°
1061	Jan. 6·74	263	9·83	0	...	+ 9·83	9·83
1062	Feb. 3·08	535	12·51	2	11·58	+12·41	12·51
1063	Mar. 2·42	162	8·67	0	...	+ 8·67	8·67
1064	29·73	28	5·59	0	...	+ 5·59	5·59
1065	Apr. 26·00	14	10·80	0·4	5·42	+10·30	10·64
1066	May 23·23	33	6·04	2	7·00	+ 5·38	6·08
1067	June 19·43	24	7·11	1	3·90	+ 6·63	6·97
1068	July 16·63	0·1	3·00	0·2	13·10	− 6·70	9·10
1069	Aug. 12·85	1	5·52	10	10·00	− 8·83	9·66
1070	Sept. 9·09	4	14·51	8	4·72	+ 1·48	7·87
1071	Oct. 6·37	45	8·84	1	31·50	+ 8·37	9·10
1072	Nov. 2·66	0	...	0	...	...	...
1073	29·97	1	0·90	0	...	+ 0·90	0·90

TABLE IV

Year	No. of Days on which Sun was photographed	Spots North of the Equator		Spots South of the Equator		Mean Latitude of entire Spotted Area	Mean Distance from Equator of all Spots
		Mean Daily Area	Mean Heliographic Latitude	Mean Daily Area	Mean Heliographic Latitude		
			°		°	°	°
1923	365	33	13·88	22	17·32	+ 1·34	15·26
1924	366	232	22·19	45	25·54	+14·49	22·73
1925	365	517	20·70	313	19·37	+ 5·60	20·20
1926	365	663	19·27	599	17·98	+ 1·60	18·66
1927	365	379	17·75	679	13·54	− 2·33	15·05
1928	366	727	11·93	663	15·23	− 1·02	13·50
1929	365	656	10·73	586	10·27	+ 0·82	10·51
1930	365	286	10·60	230	8·96	+ 1·88	9·87
1931	365	200	7·91	75	9·39	+ 3·21	8·31
1932	366	123	8·22	40	8·62	+ 4·06	8·32
1933	365	86	10·60	2	8·35	+10·23	10·56

The rotations in Tables I and III are numbered in continuation of Carrington's series.

The chief features of the record of sunspots and faculæ for the year 1933 are as follows :—

1. The occurrence of activity characteristic in general of the minimum of the 11-year cycle, namely, (*a*) infrequent sunspots and faculæ in low latitudes, (*b*) periods of almost complete quiescence, (*c*) the beginning of small, high-latitude spots of the new cycle. A notable exception was the appearance of a large group of spots from February 1 to 13 in latitude $+13°$, which in area contributed 35 millionths of the Sun's hemisphere to the mean daily area of 88 millionths for the year 1933 as a whole.

2. On 234 days no spots were recorded and on 123 days no faculæ. On 105 days the disc was entirely blank.

3. The northern hemisphere was the more active, which has been the case for eight out of the ten years of the present cycle (1924 to 1933).

4. The mean latitude of spots ($10°{\cdot}6$) irrespective of sign is $2°{\cdot}2$ higher than in 1932, but the occurrence of the large group in latitude $13°$ is chiefly responsible for this anomaly. Omitting the large group, the mean latitude is $8°{\cdot}8$. Two high latitude spots belonging to the new cycle were both small; their respective latitudes were $+27°$ (Oct. 10) and $-31°$ (Oct. 29).

5. The number of groups lasting for two days or longer was 30; of these, 24 were in the northern hemisphere and 6 in the southern. In addition, there were 20 very small groups recorded on one day only; 17 were north and 3 south of the equator.

Royal Observatory, Greenwich:
1934 *August* 9.

OCCULTATIONS OF STARS BY THE MOON, OBSERVED AT THE NIZAMIAH OBSERVATORY, HYDERABAD, DURING THE YEAR 1933.

(Communicated by the Director)

No.	Star	Mag.	Phase	Date 1933	G.C.T. h m s
1	A.G. Strassburg 7990	9·0	D	Jan. 1	14 10 55·2
2	B.D. $-5°{\cdot}5949$	9·5	D	1	14 46 10·5
3	A.G. Nicolajew 5915	9·4	D	2	13 26 10·7
4	B.D. $+0°{\cdot}5075$	9·5	D	2	15 3 14·4
5	B.D. $+1°{\cdot}4809$	9·3	D	2	15 45 56·3
6	B.D. $+1°{\cdot}4810$	9·3	D	2	15 54 35·7
7	A.G. Albany 8221	9·1	D	2	15 58 4·0
8	14 H Tauri	5·3	D	7	14 51 49·4
9	A.G. Berlin 810	9·0	D	Feb. 2	14 12 11·3
10	A.G. Berlin 815	8·2	D	2	15 30 52·5
11	7 Tauri	5·9	D	3	16 27 31·0
12	47 Geminorum	5·6	D	7	15 35 9·6
13	A.G. Cambridge 2229	8·9	D	Mar. 4	14 5 34·7
14	β Tauri	1·7	D	Apr. 1	10 3 23·3
15	A.G. Cambridge 3918	7·9	D	3	14 35 32·5
16	48 G. Sagittari	6·3	D	Sept. 26	16 15 3·7
17	13 Piscium	6·4	D	Oct. 29	14 44 15·5
18	26 Arietis	6·2	D	Nov. 29	16 15 54·6

All the observations were made by M. K. Bappu with the exception of Nos. 9 and 14 which were observed by T. P. Bhaskaran. The instrument used was the 15-inch Grubb refractor and the times were in all cases noted with a stop-watch; the clock corrections were determined from observations with the transit instrument.

Nos. 9 and 10 were observed through thin clouds.

The reductions have been carried out in duplicate by M. V. V. Sastri and S. Aravamudan according to the method adopted by the *Nautical Almanac* office. As suggested by Professor Brown, a correction of $0^h.0025$ has been added to the G.C.T. to allow for the error of 5″ in the mean longitude of the Moon.

No.	χ	ρ	$\sigma' - \sigma$	Cos $(\chi - \rho)$
	° ′	° ′	″	
1	341 4	62 4	−0·9	+0·156
2	57 10	62 2	+0·5	+0·996
3	12 30	61 44	−2·8	+0·653
4	76 42	61 45	0·0	+0·966
5	351 58	61 46	+0·9	+0·345
6	26 17	61 46	−0·7	+0·814
7	103 52	61 46	−1·2	+0·742
8	8 13	76 24	+3·1	+0·372
9	73 52	69 58	−2·5	+0·998
10	50 39	70 12	−4·6	+0·942
11	137 22	75 6	+1·4	+0·465
12	93 10	99 32	+0·5	+0·994
13	44 13	84 7	+3·6	+0·767
14	24 1	87 18	−0·9	+0·450
15	109 37	100 59	+1·8	+0·989
16	123 22	85 26	+3·5	+0·789
17	73 34	62 15	−0·7	+0·980
18	104 52	70 10	−0·9	+0·822

The position of star No. 2 has been taken from San Fernando Catalogo Astrofotographico, while the places for Nos. 4, 5 and 6 were obtained from Algiers "Carte du Ciel" Catalogue.

Nizamiah Observatory,
Hyderabad, India.

OCCULTATIONS OF STARS BY THE MOON, OBSERVED AT ENGELHARDT OBSERVATORY, KASAN, DURING THE YEARS 1925–1932.

The reductions were made by J. W. Belkowitsch.

No.	Date	G.C.T.	Star	Mag.	Phenomenon	Instrument and Power	Observer	Remarks
		h m s						
1	1925 Jan. 28	17 46 33·4	Str 66	7·0	D	R 308	Dr	
2	30	17 55 30·4	Lpz. II 759	7·8	D	R 308	Dr	
3	30	17 55 29·8	,,		D	A 183	Dk	
4	Feb. 26	15 46 09·2	Alb. 450	7·7	D	R 308	Dr	
5	27	16 52 46·3	ξ^2 Ceti	4·3	D	A 110	Dk	
6	27	16 52 46·4	,,		D	R 143	Dr	
7	27	17 50 37·9	,,		R	A 110	Dk	
8	27	17 27 46·7	Lpz. II 922	8·5	D	R 143	Dr	
9	27	17 48 42·1	Lpz. II 929	8·4	D	R 143	Dr	
10	Apr. 27	17 50 51·9	64 Orionis	5·1	D	A 110	Dk	
11	27	17 50 52·3	,,		D	R 143	Dr	
12	27	18 45 22·7	,,		R	A 110	Dk	
13	28	19 25 36·4	Berl. 2492	8·7	D	R 143	Dr	
14	28	19 25 36·4	,,		D	A 110	J	
15	Aug. 1	18 27 04·8	88 Virginis	6·5	D	R 143	Dr	
16	2	18 42 47·4	198 B Sag	6·4	D	A 110	Dr	Clouds.
17	1926 Apr. 15	18 00 35·7	64 Tauri	4·9	D	H 132	J	
18	15	18 00 36·1	,,		D	R 308	Dr	Good.
19	1929 Jan. 21	15 38 16·1	τ Tauri	4·3	D	A 110	N	
20	21	15 38 16·3	,,		D	Z 64	B	
21	21	15 38 16·6	,,		D	F 108	Dk	
22	21	15 38 16·6	,,		D	R 143	T-a	
23	21	16 31 07·1	,,		R	R 143	T-a	
24	23	18 02 44·2	40 Gem	6·3	D	A 110	N	
25	23	18 02 44·5	,,		D	H 132	J	
26	23	18 02 44·5	,,		D	F 108	Dk	Uncertain.
27	23	18 02 44·7	,,		D	R 143	T-a	
28	May 22	21 43 42·4	150 B Libræ	6·1	D	R 143	B	
29	Sept. 24	18 20 29·0	315 B Tauri	6·3	D	R 143	T-a	
30	24	19 09 56·2	,,		R	R 143	T-a	
31	1930 Jan. 14	19 45 06·2	*c* Gem	5·5	R	R 143	T-a	
32	Feb. 10	19 02 42·4	BD +26°1481	7·0	D	R 143	B	Uncertain.
33	Apr. 6	20 27 48·5	BD +26°1621	9·4	D	A 110	N	
34	6	20 27 48·6	,,		D	R 143	B	
35	6	20 29 11·1	BD +26°1620	9·2	D	A 110	N	
36	6	20 29 11·9	,,		D	R 143	B	
37	6	21 03 21·3	BD +26°1628	9·5	D	R 143	B	
38	6	21 03 21·5	,,		D	A 110	N	
39	6	21 30 0·7	BD +26°1630	9·0	D	A 110	N	

No.	Date	G.C.T.	Star	Mag.	Phenomenon	Instrument and Power	Observer	Remarks.
		h m s						
40	1930 Apr. 6	21 30 1·1	BD +26°1630	9·0	D	R 143	B	
41	6	21 30 2·4	,,		D	F 108	T	
42	6	22 34 3·5	*c* Gem	5·5	D	R 143	B	
43	6	22 34 3·6	,,		D	A 110	N	
44	6	22 34 3·6	,,		D	F 108	T	
45	May 3	17 34 10·3	134 B Gem	6·5	D	A 110	N	
46	3	17 34 10·7	,,		D	R 143	B	
47	4	18 08 45·7	λ Cancri	5·9	D	A 110	N	
48	4	18 08 46·1	,,		D	F 108	T	
49	4	18 08 46·1	,,		D	R 143	B	
50	4	18 37 25·6	BD +24°1913	8·5	D	F 108	T	
51	5	20 09 26·3	BD +24°2318	6·5	D	A 110	N	
52	5	20 09 26·4	,,		D	R 143	T	
53	Oct. 29	15 10 15·9	86 B Cap	6·2	D	A 110	N	Uncertain.
54	29	15 10 17·9	,,		D	R 143	T-a	
55	29	15 10 18·0	,,		D	r 58	B	
56	Nov. 2	18 37 03·1	27 Psc	5·1	D	A 110	N	
57	2	18 37 03·2	,,		D	R 143	T-a	
58	2	21 01 42·6	29 Psc	5·1	D	R 143	T	
59	2	21 01 42·7	,,		D	A 110	A	
60	1931 Jan. 1	13 50 20·0	161 B Tauri	6·5	D	R 143	T-a	
61	26	17 10 36·5	12 H^1 Arietis	6·3	D	A 110	A	Uncertain.
62	26	17 10 39·2	,,		D	R 143	T-a	
63	26	17 10 39·6	,,		D	F 108	J	
64	27	15 58 03·8	40 Arietis	6·0	D	F 108	J	
65	27	15 58 03·9	,,		D	H 132	B	
66	30	14 36 56·4	107 B Aur	6·5	D	F 108	T	
67	30	14 36 56·4	,,		D	R 143	T-a	
68	30	14 36 56·7	,,		D	A 110	J	
69	30	22 26 34·5	136 Tauri	4·6	D	R 143	T-a	
70	30	22 26 34·7	,,		D	F 108	T	
71	30	22 26 34·9	,,		D	A 110	N	
72	30	22 26 34·9	,,		D	H 132	B	
73	30	22 26 35·0	,,		D	Z 64	J	
74	Feb. 24	14 53 56·2	τ Arietis	5·1	D	A 110	Dk	
75	24	14 53 56·5	,,		D	H 132	B	
76	24	14 53 56·6	,,		D	F 108	T	
77	24	14 53 56·8	,,		D	R 143	T-a	
78	24	16 02 55·0	,,		R	A 110	Dk	
79	24	16 02 55·4	,,		R	R 143	T-a	
80	Mar. 27	21 58 54·4	47 Gem		D	R 143	T-a	
81	27	21 58 55·2	,,		D	A 110	T	
82	28	16 25 07·3	ω Cancri	6·1	D	H 132	B	
83	28	16 25 09·3	,,		D	R 143	T	
84	28	17 05 09·6	4 Cancri	6·2	D	H 132	B	
85	28	17 05 10·5	,,		D	R 143	T	
86	28	18 03 59·2	,,		R	R 143	T	
87	Apr. 24	16 52 52·4	*c* Gem	5·5	D	A 110	N	
88	24	16 52 52·5	,,		D	R 143	T-a	
89	24	17 42 21·5	,,		R	R 143	T-a	
90	24	17 17 40·6	Cambr. 4152	8·1	D	R 143	T-a	

No.	Date	G.C.T.	Star	Mag.	Phenomenon	Instrument and Power	Observer	Remarks.
		h m s						
91	1931 Apr. 24	17 17 40·7	Cambr. 4152	8·1	D	A 110	N	
92	24	17 17 41·0	,,		D	F 108	T	
93	24	18 12 48·8	Cambr. 4161	8·6	D	F 108	T	Uncertain.
94	24	18 12 48·9	,,		D	A 110	N	
95	24	18 12 49·3	,,		D	R 143	T-a	
96	24	17 59 16·7	Cambr. 4160	9·0	D	R 143	T-a	
97	24	18 01 09·9	Cambr. 4158	9·4	D	R 143	T-a	
98	Oct. 23	21 02 36·7	80 B Psc	6·3	D	R 143	T-a	$+0^{s}.2$?
99	28	18 04 36·9	104 B Tauri	5·5	D	R 143	T-a	
100	1932 Feb. 16	20 38 04·2	354 B Tauri	6·4	D	R 143	T-a	Uncertain.
101	16	20 38 04·9	,,		D	H 132	B	

The time-corrections of the chronometer in Nos. 1–14, 29, 30, 45–52 were determined from observations. In other cases they were found from the Bordeaux, Rugby and Nauen wireless signals.

Observers :
Dk = J. A. Dukov.
Dr = K. K. Dubrovsky.
J = A. A. Jakovkin.
B = J. W. Belkowitsch.
N = Miss S. W. Nekrasova.
T-a = Mrs. N. A. Tchudowitchewa.
T = N. J. Tchudowitchew.
A = Mrs. L. D. Agafonowa.

Instruments used :
A = Astrographic (110 mm.).
F = Fraunhofer telescope (98 mm.).
H = Heliometer (106 mm.).
R = Refractor (306 mm.).
r = Refractor (finder) (135 mm.).
Z = Zeiss telescope (68 mm.).

Engelhardt Observatory :
1934 *May.*

LIST OF ADDITIONS

TO THE

LIBRARY OF THE SOCIETY

1933 JULY 1 TO 1934 JULY 31

Serial Publications received by exchange in the regular course, and Reprints of Papers published in some of these Serials, are not included in this Annual List.

Unless otherwise indicated, the donor is the author or the Institution concerned.

An asterisk (*) *indicates that the work is an excerpt.*
A dagger (†) *indicates that the work has been purchased.*

Abbadia, Observatoire :

Cinquième catalogue comprenant 1275 étoiles, dont 669 fondamentales, de $+45°$ à $-26°$, observées en 1928, 1929. Réduites à 1925·0.
4to. Hendaye, 1934

Allahabad, Academy of Sciences :

Bulletin, Vol. 2, No. 4 ; Vol. 3, No. 2. 8vo. Allahabad, 1933

†Amateur Telescope Making :

(A collective work.) A. G. Ingalls, Editor. With a foreword by Dr. Harlow Shapley. Third Edition. Sm. 4to. New York, 1933

American Association of Variable Star Observers :

——: Bulletin, 1933 December 15. 4to. typescript, Cambridge (Mass.), 1933

——: *Monthly Reports and Annual Report for the year 1933.
8vo. Northfield, 1933

Amsterdam, Astronomical Institute of the University :

Publications, No. 3. 4to. Amsterdam, 1933

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Anding (E.) :

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